NOTE: Heavy use of the material presented by Bevan, Meadows at the 2011 charm workshop held in Beijing, also good talks by Rama, Neri et al, Sokolof ... and recent presentations at Hawaii (Charm 2012)/ICHEP 2012.

This represents our first acknowledgement of a broad threshold programme within the context of SuperB, but is by no means comprehensive.

Unfortunately recent events mean this should be revisited to explore in more detail.

A Perspective on Physics

Adrian Bevan

LNF, Frascati, 13th December 2012

email: a.j.bevan@qmul.ac.uk

Queen Mary
University of London

The SuperB Physics Programme

- Over a number of years we have worked hard to develop a solid, broad physics programme for running at the $\Upsilon(4S)$, higher Υ resonances and at "low" energy.
  - Synergy with the energy frontier
  - Synergy with other flavour experiments
  - Wide reaching implications for model builders (once the data came in).

- This solid physics programme was the result of hard work by many people over many years:
  - experimentalist, hardware expert, machine folk and theorists all contributed to this.
    - Many thanks to you all!

The SuperB Physics Programme

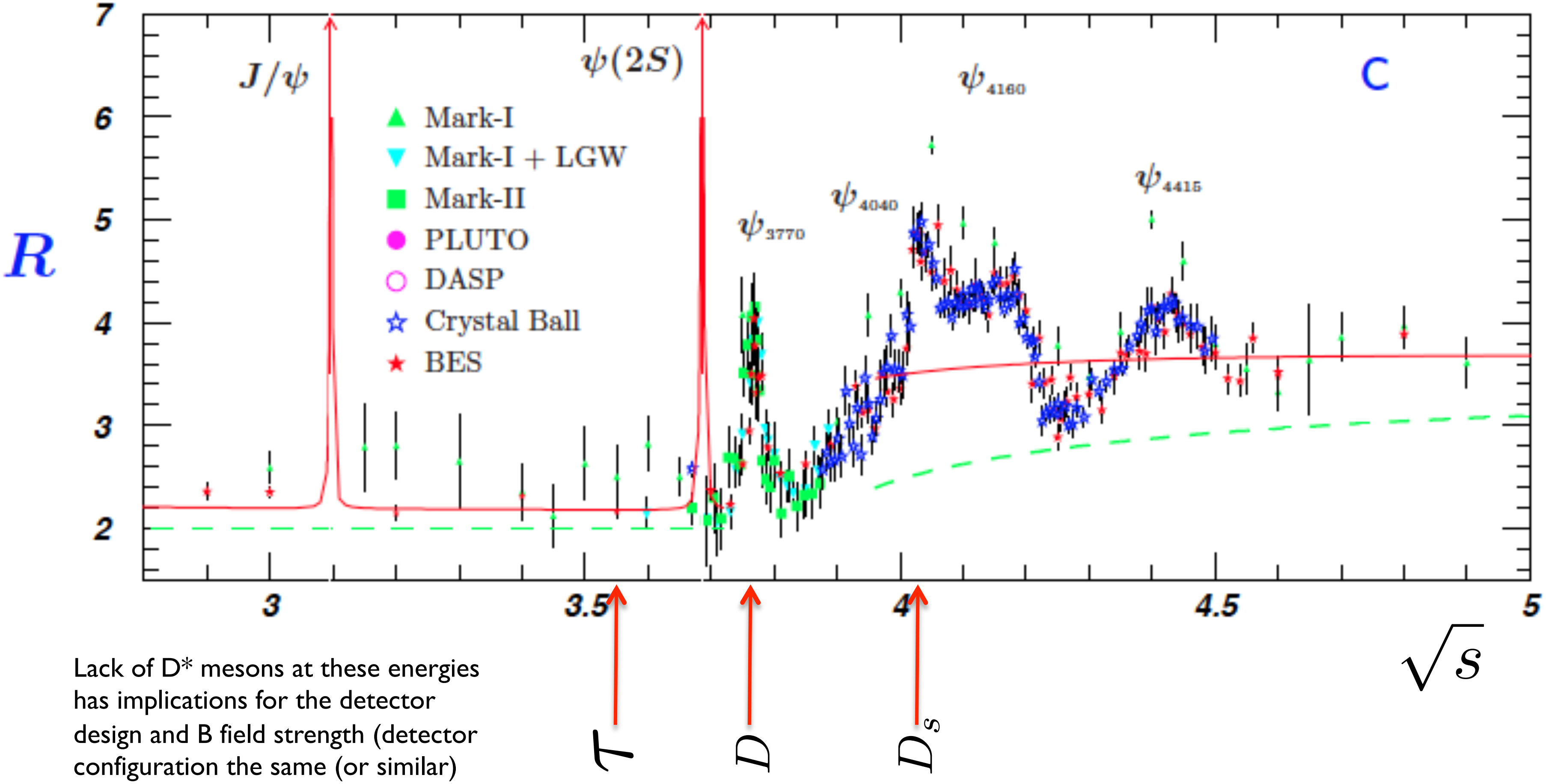
- The news of a few weeks ago was a shock to us all ...
- but the work we did is not wasted:
  - Highlighted in the detector TDR, and a number of other reports.
  - The high energy exploration will still be of use to Belle II as they move forward.
  - The low energy ideas will form the basis of what we talk about over the next few days, and perhaps form the core of a new experimental concept as people move forward.

What is low energy and what has been done so far?

Concentrating of work within our community so far…

What is low energy?

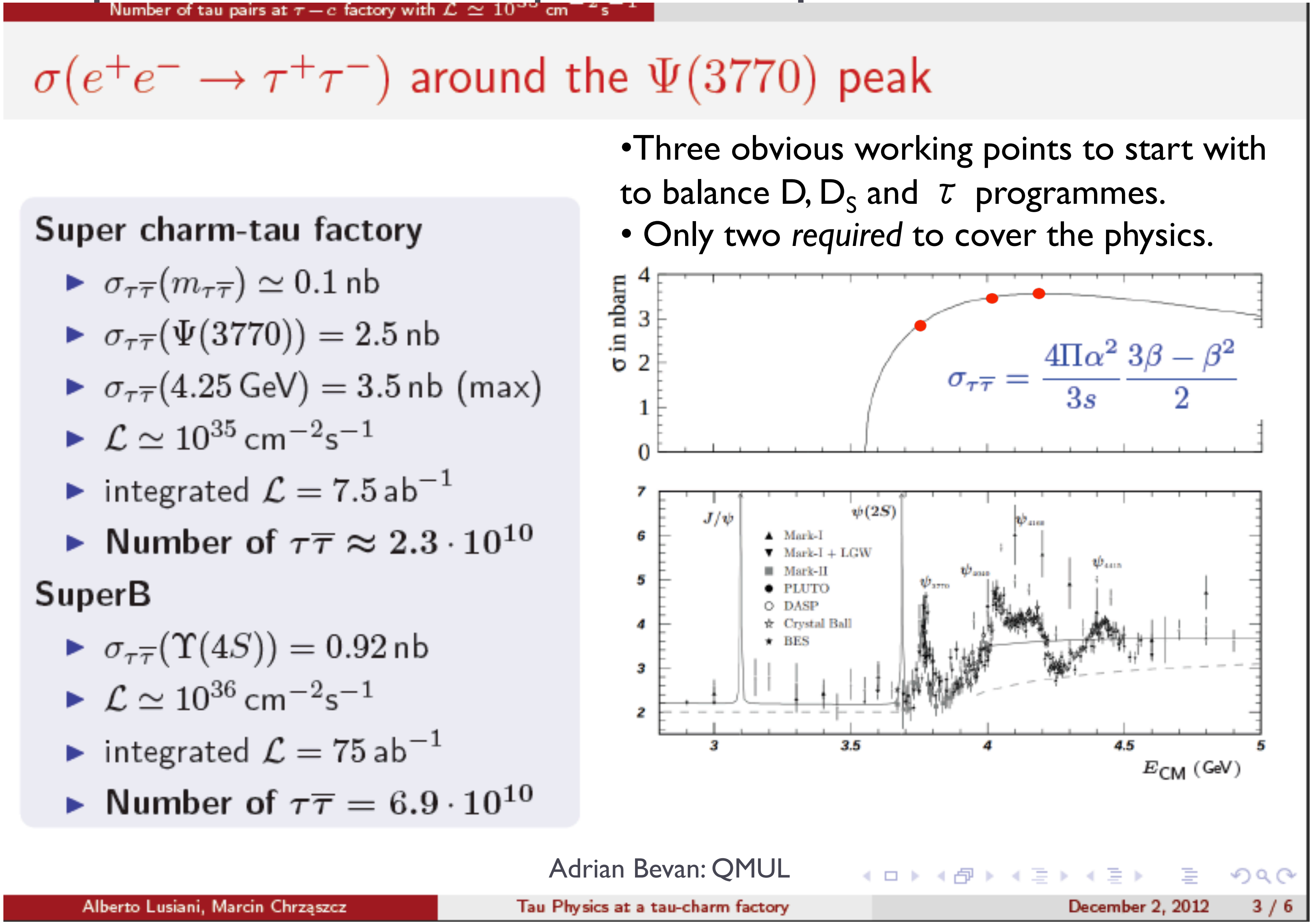
- Focus on thresholds that SuperB is (was) thinking about



Lack of D* mesons at these energies has implications for the detector design and B field strength (detector configuration the same (or similar) to 4S running).

From Bevan @ Charm WS 2011

SuperC is also a Superτ = SuperτC



Number of tau pairs at $\tau - c$ factory with $\mathcal{L} \simeq 10$ cm s

$\sigma(e^+e^- \to \tau^+\tau^-)$ around the $\Psi(3770)$ peak

- •Three obvious working points to start with to balance D, D$_S$ and τ programmes.
- Only two *required* to cover the physics.

Super charm-tau factory

- $\sigma_{\tau\overline{\tau}}(m_{\tau\overline{\tau}}) \simeq 0.1\,\mathrm{nb}$
- $\sigma_{\tau\overline{\tau}}(\Psi(3770)) = 2.5\,\mathrm{nb}$
- $\sigma_{\tau\overline{\tau}}(4.25\,\mathrm{GeV}) = 3.5\,\mathrm{nb}$ (max)
- $\mathcal{L} \simeq 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- integrated $\mathcal{L} = 7.5\,\mathrm{ab}^{-1}$
- **Number of $\tau\overline{\tau} \approx 2.3 \cdot 10^{10}$**

SuperB

- $\sigma_{\tau\overline{\tau}}(\Upsilon(4S)) = 0.92\,\mathrm{nb}$
- $\mathcal{L} \simeq 10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- integrated $\mathcal{L} = 75\,\mathrm{ab}^{-1}$
- **Number of $\tau\overline{\tau} = 6.9 \cdot 10^{10}$**

$$\sigma_{\tau\overline{\tau}} = \frac{4\Pi\alpha^2}{3s}\frac{3\beta - \beta^2}{2}$$

Adrian Bevan: QMUL

A snapshot of work done over the past few years

A number of key measurements from CLEO-c out performed BaBar and Belle…

Low energy is a clean environment to do physics in.

D tagged events analogous to fully reconstructed B physics at the 4S.

Many parallels in terms of analysis philosophy.

Quantum correlations to exploit.

What about detector optimisation?

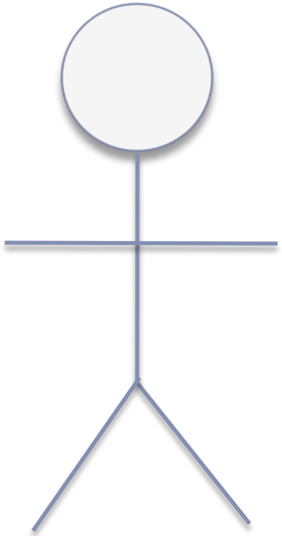
Why do CLEO-c and BES III look like they do?

What about rare decays?

Old CDR studies assuming 100fb^{-1}

TDCPV at threshold

What can be done with /ab data sets?

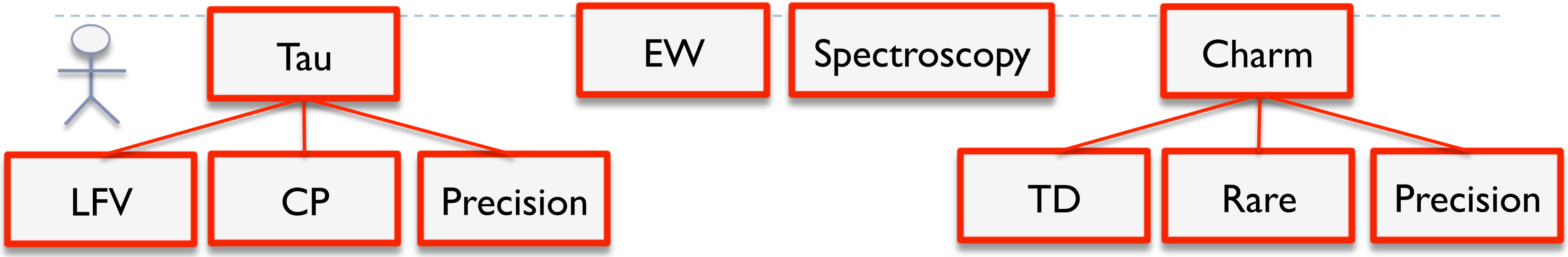


A straw man physics programme

This is a starting point – will need to be refined

In many circumstances there are no detailed estimates of precision attainable at low energy (yet)

Overview



Tau

LFV

CP

Precision

EW

Spectroscopy

Charm

TD

Rare

Precision

(Multiple energies to consider)

Physics
V
Experiment

Machine

CM Energy

Asymmetry

Polarisation

Backgrounds

Luminosity

Detector

Tracking

PID

Calorimeter

KL/ μ ID

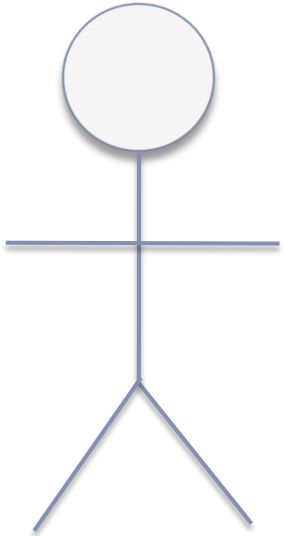
Asymmetry

DAQ

Hermiticity

Computing

See Francesco's talk later this morning

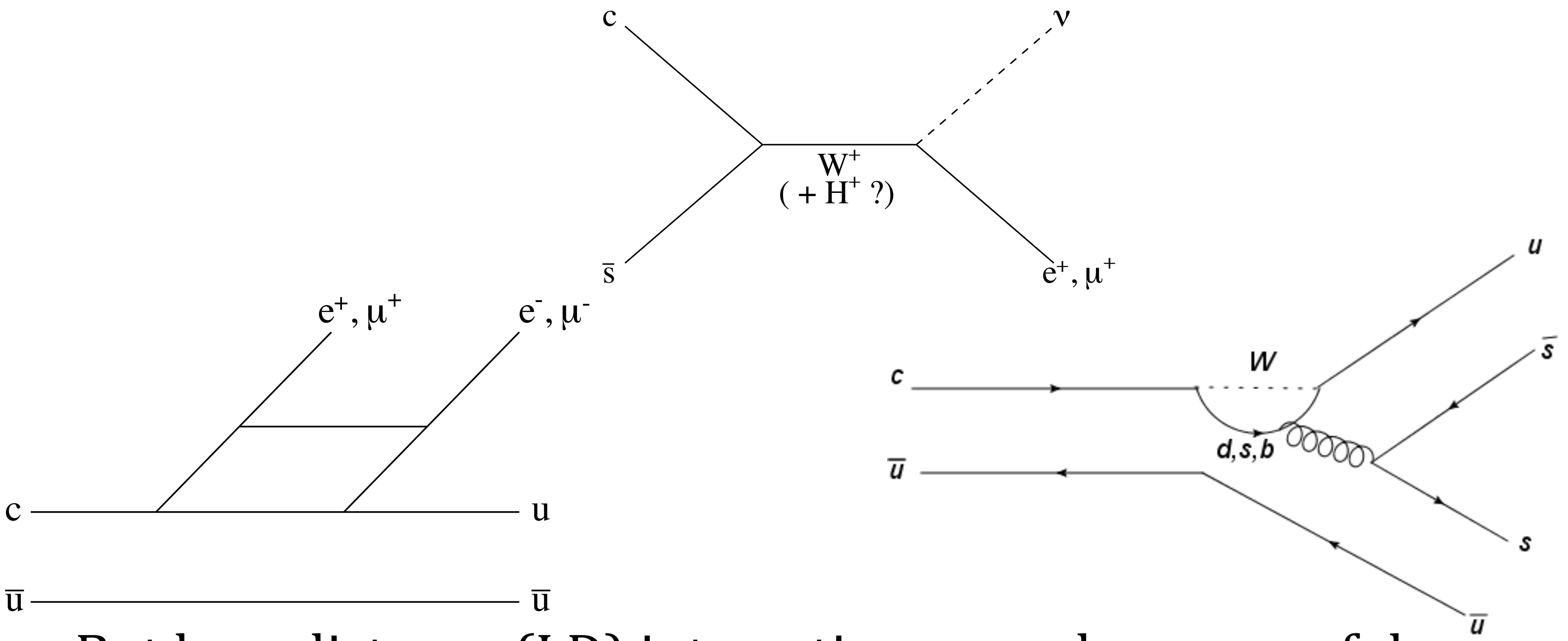


Charm

Time-dependent, rare, precision

Rare: What do we want to measure?

- NP sensitive processes
  - (or modes controlling theoretical uncertainties for these).



- But long distance (LD) interactions can obscure usefulness of the short distance (SD) ones, so not always straightforward to understand NP reach.

From Bevan @ Charm WS 2011

What is rare?

- What is rare?
  - CLEO-c at $\psi(3770)$: 0.8fb^{-1} .... sensitivity of a few $\times 10^{-5}$
  - BES III at $\psi(3770)$: $\sim 10\text{fb}^{-1}$ .... sensitivity of a few $\times 10^{-6}$
  - SuperB at $\psi(3770)$: 500fb^{-1} .... sensitivity of a few $\times 10^{-8}$
    - Two large jumps in data samples could change the perspective on rare decays with time ...
    - SuperB will approach a single event sensitivity at $\sim 10^{-9}$ at threshold

  - BaBar/Belle at the $\Upsilon(4S)$: $\sim 0.5\text{-}1\text{ab}^{-1}$ of data [60-1.2 $\times 10^{9}$ events]
  - SuperB/Belle II at the $\Upsilon(4S)$: $50\text{-}75\text{ab}^{-1}$ of data [60-90 $\times 10^{9}$ events]
    - Rely on D* tagged mesons, not always the best (but with 50 times more data than at threshold)

  - LHCb:
    - Vast numbers in a hadronic environment: good for charged track final states if channel can be triggered on efficiently.
    - Not so good with neutral final states (ν's, γ's, π^0's etc.)

From Bevan @ Charm WS 2011

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    - Two large jumps in data samples could change the perspective on rare decays with time

SuperτC is looking at ~3/ab at threshold, so ~10^{10} charm decays, may be able to reach a SES of a few 10^{-9}

more data than at threshold)

  - LHCb:
    - Vast numbers in a hadronic environment: good for charged track final states if channel can be triggered on efficiently.
    - Not so good with neutral final states (ν's, γ's, π^0's etc.)

From Bevan @ Charm WS 2011

$D \to \gamma\gamma$

- Dominated by long distance effects as

$$\begin{aligned}\mathcal{B}(D^0 \to \gamma\gamma)_{SD} &= 3.0 \times 10^{-11} \\ \mathcal{B}(D^0 \to \gamma\gamma)_{LD} &= (1.0 \pm 0.5) \times 10^{-8}\end{aligned}$$

Burdman/Fajfer

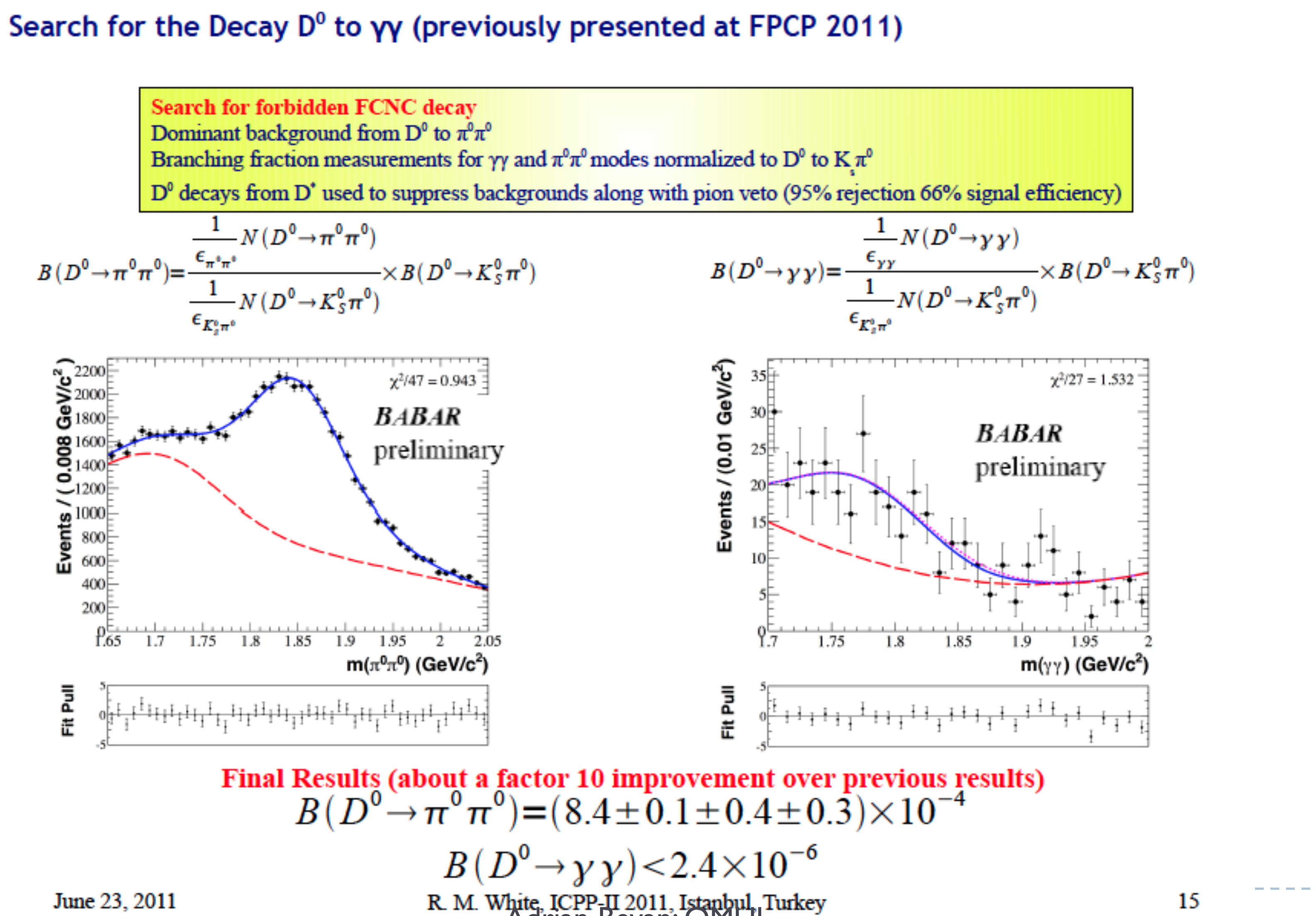
  - VMD model based calculations suggest a slightly larger BF.
  - Rate can be enhanced by New Physics.
- Rate is related to the rare di-lepton decay via:

$$\mathcal{B}(D^0 \to \mu^+\mu^-)_{LD} = 3.0 \times 10^{-5} \times \mathcal{B}(D^0 \to \gamma\gamma)$$

- BES III would reach a limit of 0.5×10^{-7} with 20fb^{-1} of data.
- SuperB should be able to reach a sensitivity of $\sim10^{-7}$ (current limit from CLEO $<2.7\times10^{-5}$).
  - Should be good enough to place a strong constraint on the di-muon mode LD contribution.
  - Potential backgrounds include $\pi^0\pi^0$, $\pi^0\eta$, $\eta\eta$, charged semi-leptonic decays.

From Bevan @ Charm WS 2011

$D \to \gamma\gamma$



Search for the Decay D^0 to γγ (previously presented at FPCP 2011)

Search for forbidden FCNC decay

Dominant background from D^0 to $\pi^0\pi^0$

Branching fraction measurements for γγ and $\pi^0\pi^0$ modes normalized to D^0 to $K_s\pi^0$

D^0 decays from D^* used to suppress backgrounds along with pion veto (95% rejection 66% signal efficiency)

$$B(D^0\to\pi^0\pi^0)=\frac{\frac{1}{\epsilon_{\pi^0\pi^0}}N(D^0\to\pi^0\pi^0)}{\frac{1}{\epsilon_{K_S^0\pi^0}}N(D^0\to K_S^0\pi^0)}\times B(D^0\to K_S^0\pi^0)$$

$$B(D^0\to\gamma\gamma)=\frac{\frac{1}{\epsilon_{\gamma\gamma}}N(D^0\to\gamma\gamma)}{\frac{1}{\epsilon_{K_S^0\pi^0}}N(D^0\to K_S^0\pi^0)}\times B(D^0\to K_S^0\pi^0)$$

Final Results (about a factor 10 improvement over previous results)

$$B(D^0\to\pi^0\pi^0)=(8.4\pm0.1\pm0.4\pm0.3)\times10^{-4}$$

$$B(D^0\to\gamma\gamma)<2.4\times10^{-6}$$

June 23, 2011 R. M. White, ICPP-II 2011, Istanbul, Turkey 15

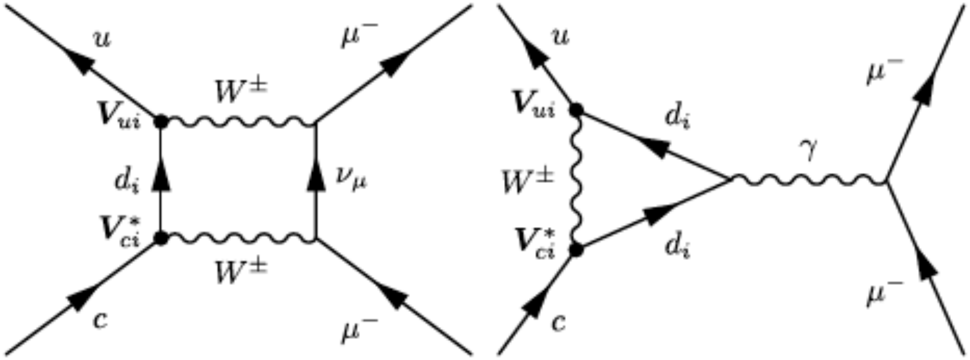
From Bevan @ Charm WS 2011

$D \rightarrow \ell^+\ell^-$

- Expect a low rate in the SM.
  - SD contribution $\sim 10^{-18}$ (Burdman et al.)
  - LD contribution related to D→γγ

$$\mathcal{B}(D^0 \rightarrow \mu^+\mu^-)_{LD} \quad = \quad 3.0 \times 10^{-5} \times \mathcal{B}(D^0 \rightarrow \gamma\gamma)$$

- SD contributions allow for possible NP enhancements:



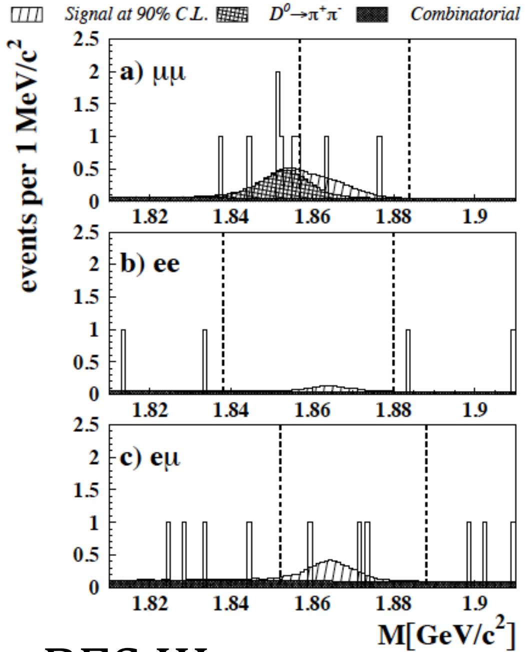
arXiv:1003.2345

  - But we need to understand LD rate in order to interpret any signals found.

From Bevan @ Charm WS 2011

$D \to \ell^+\ell^-$

- Recent results from Belle:



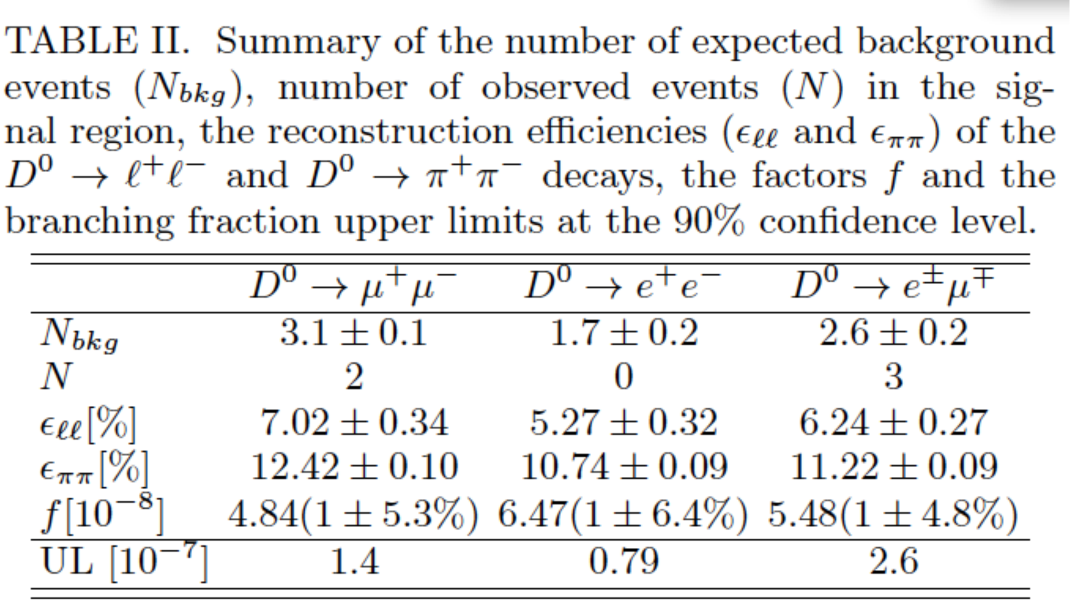


TABLE II. Summary of the number of expected background events (N_{bkg}), number of observed events (N) in the signal region, the reconstruction efficiencies ($\epsilon_{\ell\ell}$ and $\epsilon_{\pi\pi}$) of the $D^0 \to \ell^+\ell^-$ and $D^0 \to \pi^+\pi^-$ decays, the factors f and the branching fraction upper limits at the 90% confidence level.

	$D^0 \to \mu^+\mu^-$	$D^0 \to e^+e^-$	$D^0 \to e^\pm\mu^\mp$
N_{bkg}	3.1 ± 0.1	1.7 ± 0.2	2.6 ± 0.2
N	2	0	3
$\epsilon_{\ell\ell}[\%]$	7.02 ± 0.34	5.27 ± 0.32	6.24 ± 0.27
$\epsilon_{\pi\pi}[\%]$	12.42 ± 0.10	10.74 ± 0.09	11.22 ± 0.09
$f[10^{-8}]$	$4.84(1 \pm 5.3\%)$	$6.47(1 \pm 6.4\%)$	$5.48(1 \pm 4.8\%)$
UL $[10^{-7}]$	1.4	0.79	2.6

arXiv:1003.2345

- BES III expects to reach 2-17×10^{-8} with 20fb^{-1}.
- SFFs should reach limits of ~10^{-8}. ← @4S – need to estimate for CT
- LHCb expected to encounter a wall from systematic errors at ~ 2.4 × 10^{-8}... they have a clean environment, so may push further than we expected: should revisit this assumption.

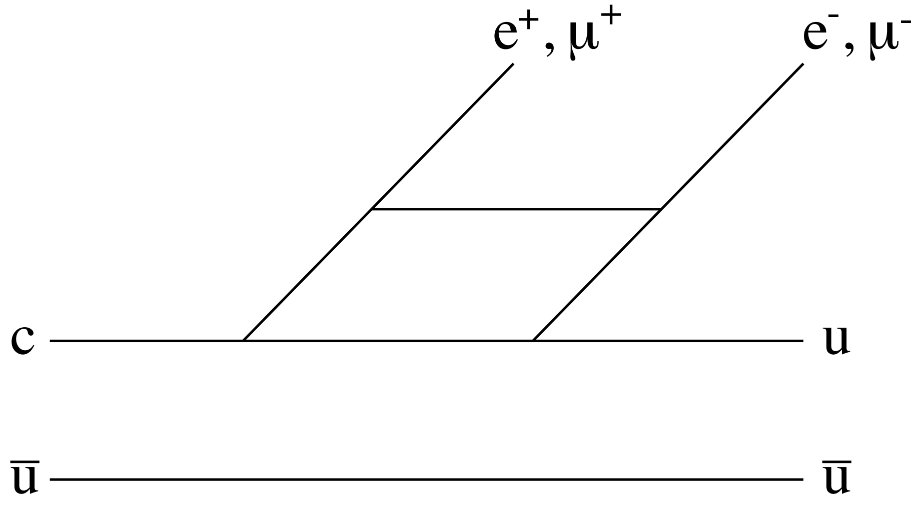
From Bevan @ Charm WS 2011

From Bevan @ Charm WS 2011

$D \to u\ell^+\ell^-$

- Inclusive branching fraction ~0.8×10^{-8} [charged rate ~×2]

$$\frac{d\Gamma_{c\to u\ell^+\ell^-}}{d\hat{s}} = \tau_D \frac{G_F^2\alpha^2 m_c^6}{768\pi^5}(1-\hat{s})^2\Bigg[\left(\left|C_9^{(\prime)\ \mathrm{eff}}(m_c)\right|^2+|C_{10}|^2\right)(1+2\hat{s}) \\ +12\ C_7^{\mathrm{eff}}(m_c)\ \mathrm{Re}\left[C_9^{(\prime)\ \mathrm{eff}}(m_c)\right]+4\left(1+\frac{2}{\hat{s}}\right)\left|C_7^{\mathrm{eff}}(m_c)\right|^2\Bigg]$$



+ LD contributions.

Differential rate is dominated by contributions from Φ and ω resonances.

LD saturates SD effects, but NP enhancements can be clearly determined (away from resonant structure).

Burdman & Shipsey hep-ph/0310076

$D \to \nu\overline{\nu}(+\gamma)$

- Helicity suppressed in the Standard Model
  - BF ~ 1.1×10^{-30}
  - The final state with a photon is much more copious: 10^{-14}
  - Beyond the SM one could find significant enhancements
    - e.g. scalar particles such as DM candidates: PRD **82**:034005, 2010.
  - Require either an isolated photon in the detector ($\nu\overline{\nu}\gamma$), or nothing ....
    - Experimentally challenging: backgrounds include where both particles go down the beam pipe... e.g. $D \to K\pi$
    - $\nu\overline{\nu}\gamma$ has the added advantage of the photon (and smaller allowed phase space for NP).
    - Also worth searching for the corresponding D_s decays ... see next topic.

+ Analogues for $B_{d,s}$ and K decays

From Bevan @ Charm WS 2011

$D \to X_u \nu\overline{\nu}$

- Similar to the invisible decay searches...
  - Can perform inclusive or exclusive measurements, both sets of measurements will provide more information to constrain NP.
    - Analogy with $B \to X\nu\overline{\nu}$
    - Similar interest for $D_s \to X_s\nu\overline{\nu}$
  - LD contributions should be small, and SM rate is tiny

$$\begin{aligned} \mathcal{B}(D^+ \to X_u\nu\overline{\nu}) &\simeq 1.2 \times 10^{-15} \\ \mathcal{B}(D^0 \to X_u\nu\overline{\nu}) &\simeq 5 \times 10^{-16} \end{aligned}$$

Bigi & Paul arXiv:1110.2862

From Bevan @ Charm WS 2011

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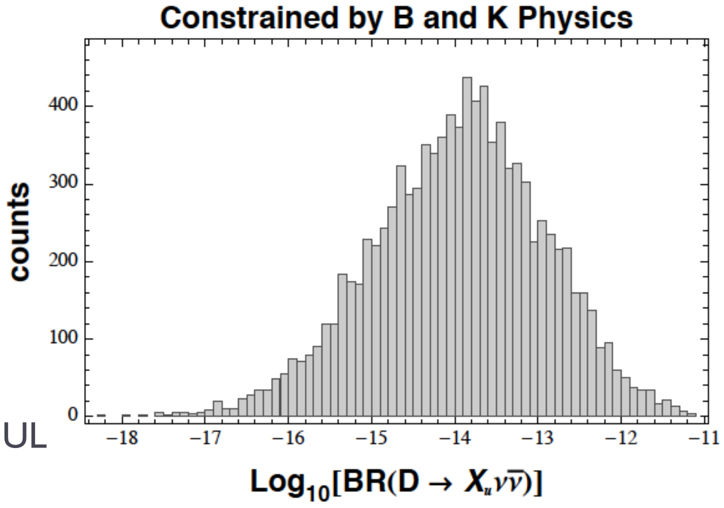
• Large enhancements possible in NP models

- Up to ×1000 in LHT models

• Plausibly could reach ~10^{-8} with SuperB at threshold, need to study potential for D* tagged samples.

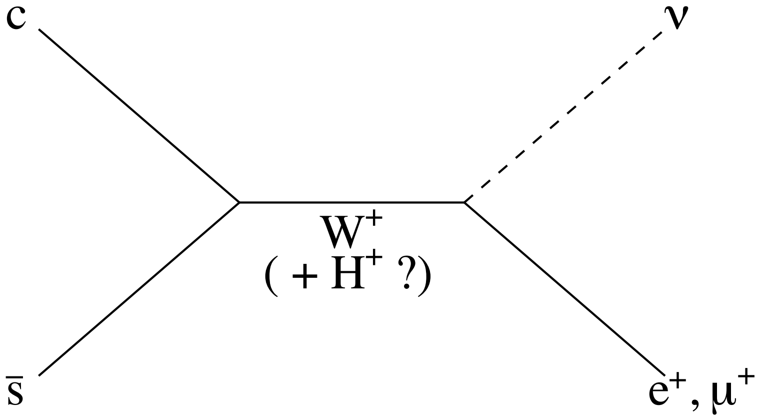
• π^0 mode is worth searching for as an indication for CPV.



Bigi & Paul arXiv:1110.2862

$D^+_{(s)} \to \ell^+\nu_\ell$

- Complementary to $B^+ \to \ell^+\nu_\ell$



$$\Gamma(D^+ \to \ell^+\nu) = \frac{G_F^2}{8\pi} f_{D^+}^2 m_\ell^2 M_{D^+} \left(1 - \frac{m_\ell^2}{M_{D^+}^2}\right)^2 |V_{cd}|^2$$

$$\Gamma(D_s^+ \to \ell^+\nu) = \frac{G_F^2}{8\pi} f_{D_s^+}^2 m_\ell^2 M_{D_s^+} \left(1 - \frac{m_\ell^2}{M_{D_s^+}^2}\right)^2 |V_{cs}|^2$$

- Can also test lepton universality with ratios of rates.

- Lots of excitement a few years ago because of a discrepancy with f_{Ds} from lattice ... unfortunately this was not a sign of NP.
- CLEO find:

$$\begin{aligned}\mathcal{B}(D_s^+ \to e^+\nu) &= < 1.2 \times 10^{-4} (90\%\, C.L.)\\ \mathcal{B}(D_s^+ \to \mu^+\nu) &= (0.565 \pm 0.045 \pm 0.017)\%\\ \mathcal{B}(D_s^+ \to \tau^+\nu) &= (6.42 \pm 0.81 \pm 0.18)\%\end{aligned}$$

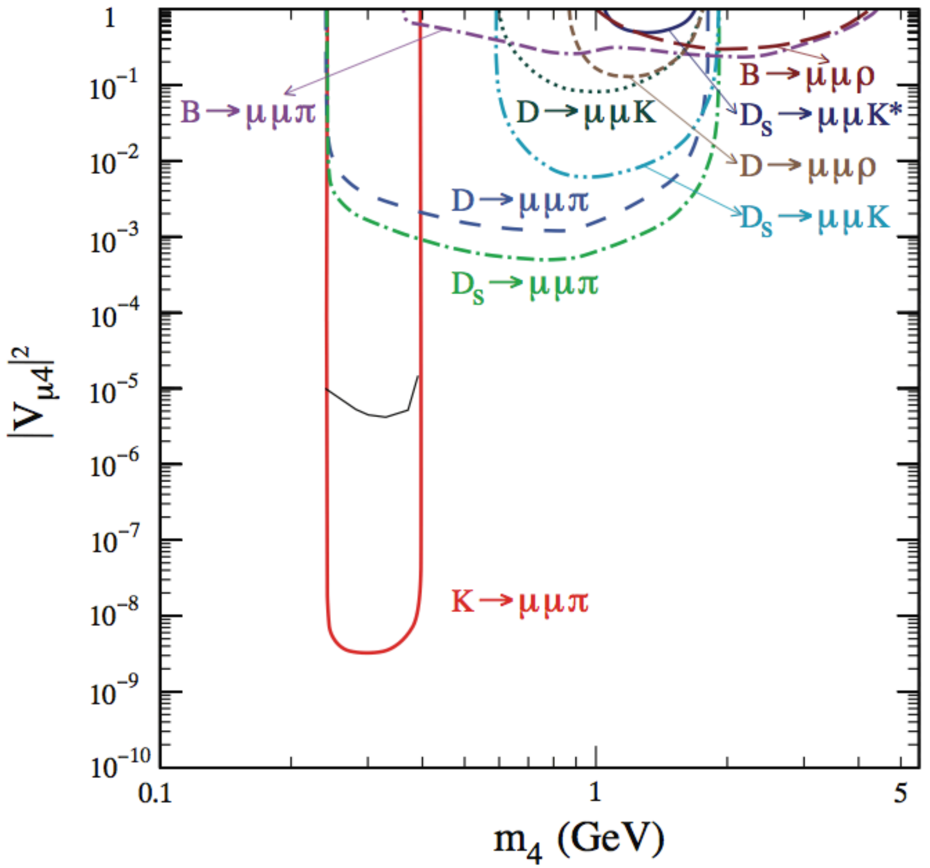
- which are compatible with SM expectations.

Phys. Rev. D**79** 052001 (2009)

From Bevan @ Charm WS 2011

Majorana neutrino tests

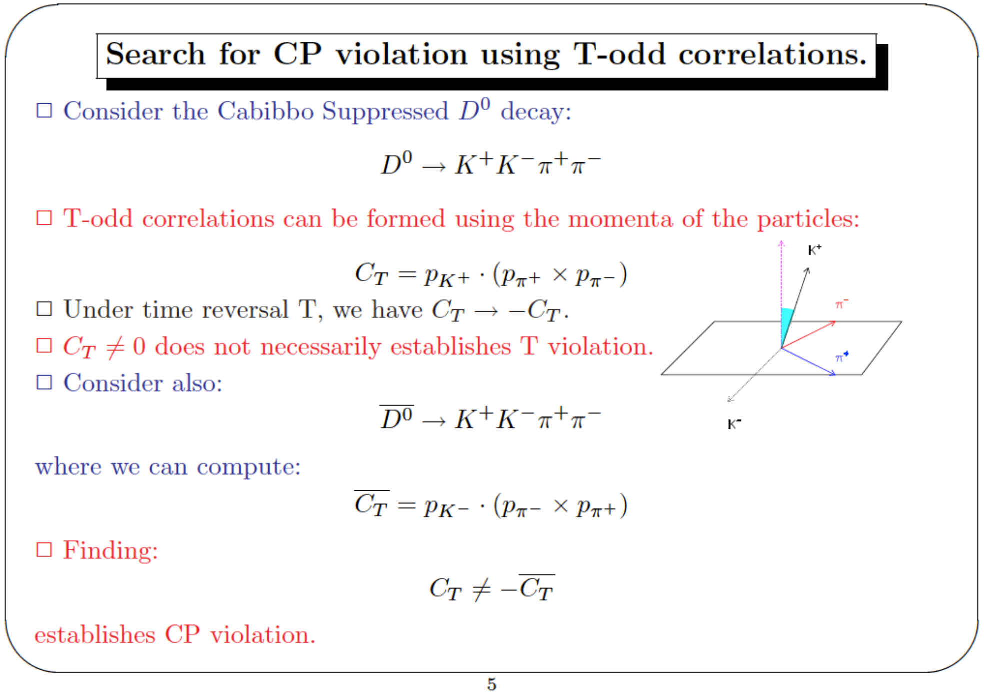
- Rare charm decays could provide complimentary tests of the neutrino nature.
- Interesting if performed on a relevant timescale (compared with direct searches for 0νββ searches).



A. Atre, T. Han, S. Pascoli, and B. Zhang, JHEP, 0905:030 (2009) [arXiv:0901.3589];
A. Atre, V. Barger and T. Han, Phys. Rev. D71, 113014 (2005) [arXiv:hep-ph/0502163]

T-odd asymmetries: $D \to KK\pi\pi$

- Triple product (CP violating) T-odd asymmetries
  - c.f. $K_{L,S} \to \pi^+\pi^-e^+e^-$



Search for CP violation using T-odd correlations.

☐ Consider the Cabibbo Suppressed D^0 decay:

$$D^0 \to K^+K^-\pi^+\pi^-$$

☐ T-odd correlations can be formed using the momenta of the particles:

$$C_T = p_{K^+} \cdot (p_{\pi^+} \times p_{\pi^-})$$

☐ Under time reversal T, we have $C_T \to -C_T$.

☐ $C_T \neq 0$ does not necessarily establishes T violation.

☐ Consider also:

$$\overline{D^0} \to K^+K^-\pi^+\pi^-$$

where we can compute:

$$\overline{C_T} = p_{K^-} \cdot (p_{\pi^-} \times p_{\pi^+})$$

☐ Finding:

$$C_T \neq -\overline{C_T}$$

establishes CP violation.

5

Should be able to reach a precision of a few 10^{-3}.

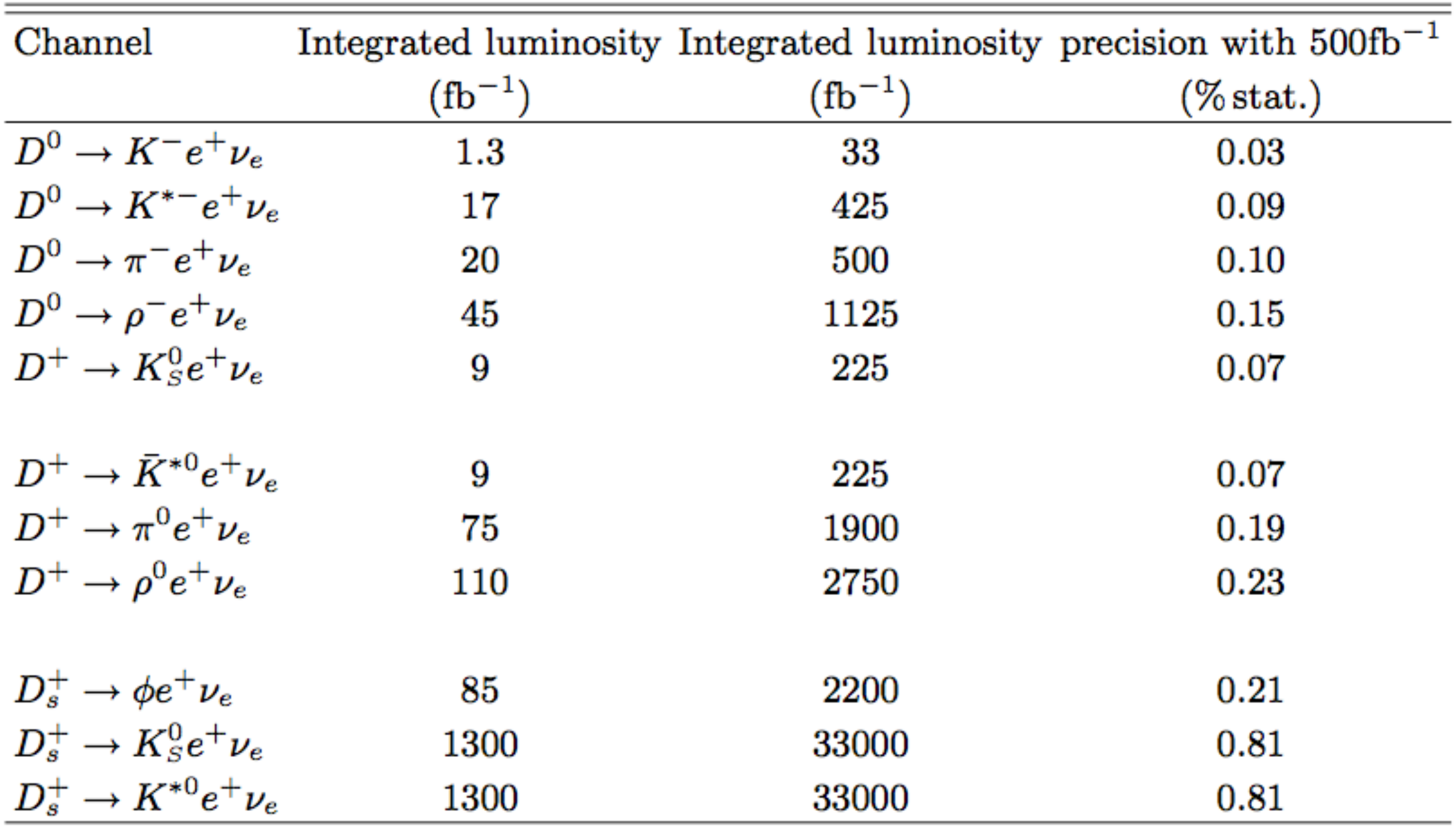
$$\begin{aligned} A_T &= \frac{\Gamma(C_T > 0) - \Gamma(C_T < 0)}{\Gamma(C_T > 0) + \Gamma(C_T < 0)} \\ \overline{A}_T &= \frac{\overline{\Gamma}(C_T > 0) - \overline{\Gamma}(C_T < 0)}{\overline{\Gamma}(C_T > 0) + \overline{\Gamma}(C_T < 0)} \\ A_{T-odd,CPV} &= \frac{1}{2}(A_T - \overline{A}_T) \end{aligned}$$

- Expect implications for the detector from this channel!

From Antimo Palano @ Warwick 2009

Rare Summary

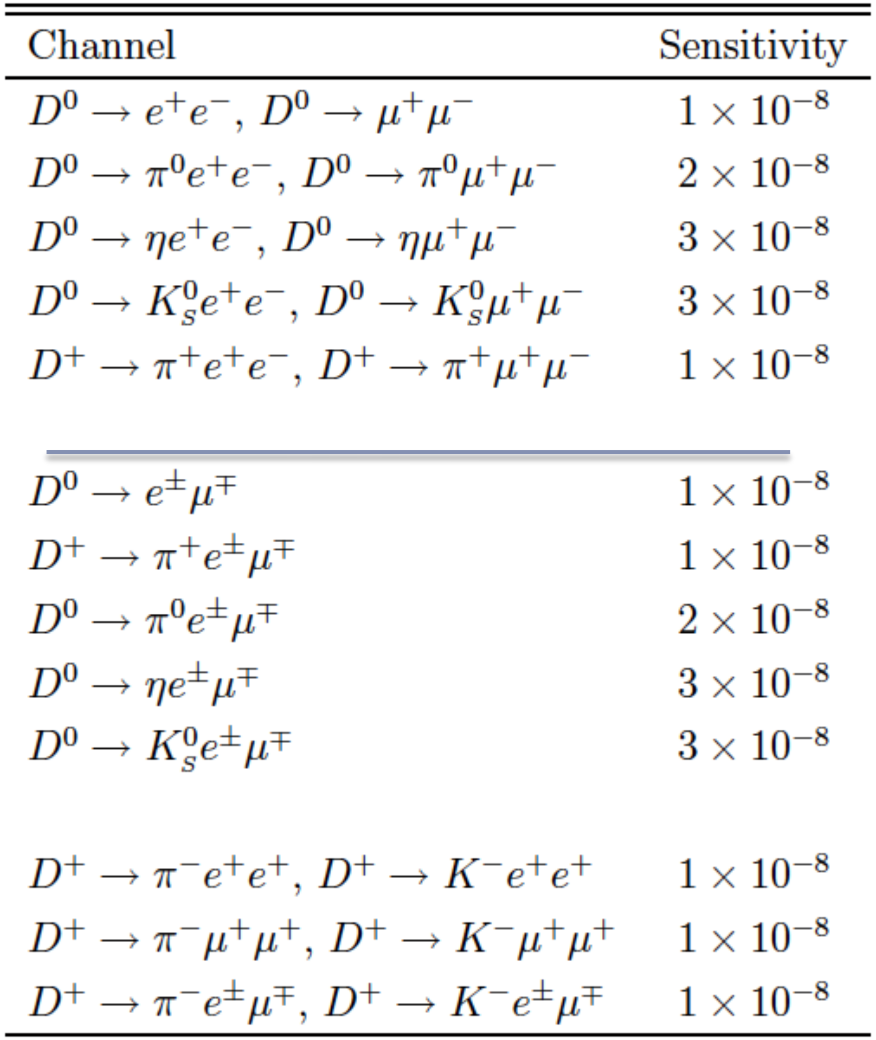
- Indication of luminosities required to reach 0.5% statistical precision on different modes vs precision at 500fb^{-1}:



Channel	Integrated luminosity (fb^{-1})	Integrated luminosity (fb^{-1})	precision with $500\mathrm{fb}^{-1}$ (% stat.)
$D^0 \to K^- e^+ \nu_e$	1.3	33	0.03
$D^0 \to K^{*-} e^+ \nu_e$	17	425	0.09
$D^0 \to \pi^- e^+ \nu_e$	20	500	0.10
$D^0 \to \rho^- e^+ \nu_e$	45	1125	0.15
$D^+ \to K^0_S e^+ \nu_e$	9	225	0.07
$D^+ \to \bar{K}^{*0} e^+ \nu_e$	9	225	0.07
$D^+ \to \pi^0 e^+ \nu_e$	75	1900	0.19
$D^+ \to \rho^0 e^+ \nu_e$	110	2750	0.23
$D_s^+ \to \phi e^+ \nu_e$	85	2200	0.21
$D_s^+ \to K^0_S e^+ \nu_e$	1300	33000	0.81
$D_s^+ \to K^{*0} e^+ \nu_e$	1300	33000	0.81

From Bevan @ Charm WS 2011

Rare Summary



Channel	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_S e^+e^-$, $D^0 \to K^0_S\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+ e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+ e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_S e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^- e^+e^+$, $D^+ \to K^- e^+e^+$	1×10^{-8}
$D^+ \to \pi^- \mu^+\mu^+$, $D^+ \to K^- \mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^- e^\pm\mu^\mp$, $D^+ \to K^- e^\pm\mu^\mp$	1×10^{-8}

- Great potential to search for NP and understand the rare branching fractions in charm.
- Threshold running will give SuperB another angle, and make it competitive compared to the previous generation.
  - Was not always the case with 4S for BaBar and Belle.

From Bevan @ Charm WS 2011

Rare Summary

Channel	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_S e^+e^-$, $D^0 \to K^0_S\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+ e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
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$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_S e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^- e^+e^+$, $D^+ \to K^- e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^- e^\pm\mu^\mp$, $D^+ \to K^- e^\pm\mu^\mp$	1×10^{-8}

- Great potential to search for NP and understand the rare branching fractions in charm.
- Threshold r ning will give SuperB a ngle, and make comp us generat
  - Was not a 4S for BaBar

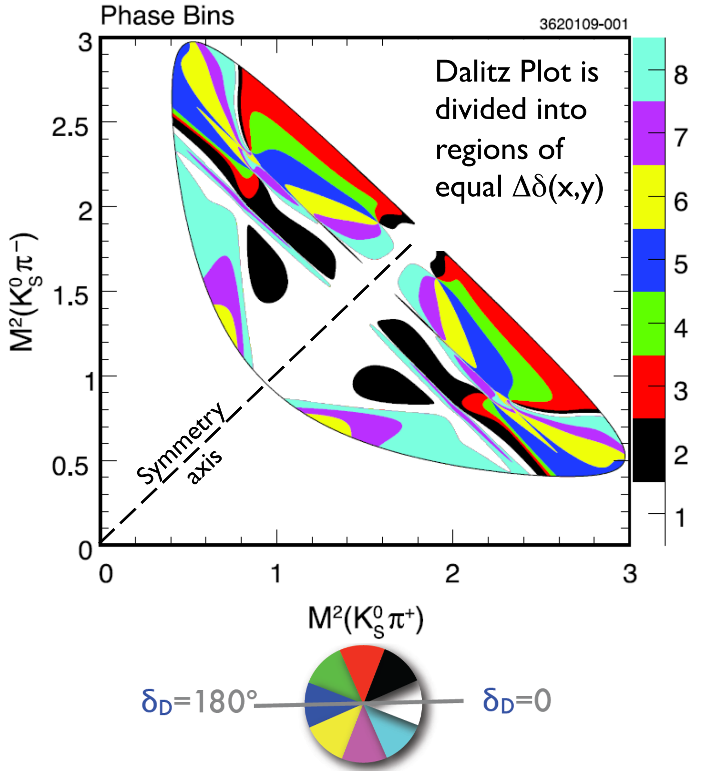
Rephrase in terms of a SuperTC

From Bevan @ Charm WS 2011

Precision Charm

- decay constants can be measured better at threshold than at the 4S: useful test of lattice.

- Strong phase map in $K_s\pi\pi$
  - Needed for gamma (GGSZ)
  - Needed for charm mixing
  - Dominated by CLEO result
  - BES III working on this measurement



- precision V_{cd}, ... + ...

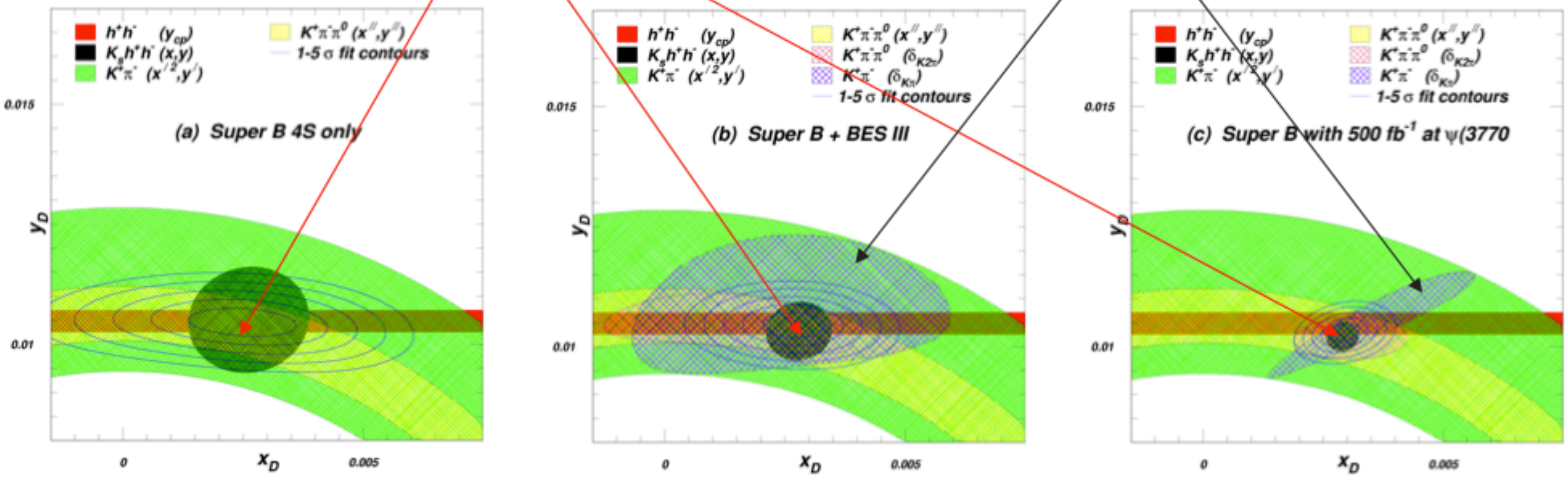
  - With regard to the issue of precision mixing measurements (see Brian Meadows) we know how powerful the D→$K_s$hh analysis is!

Value of Strong Phase Measurements

- Two improvements in mixing precision come from threshold data:

- Dalitz plot model uncertainty shrinks

- Information on overall strong phase $\delta_{K\pi}$ is added



$$x_D = (xx^{+7.2}_{-7.5}) \times 10^{-4}$$
$$y_D = (xx \pm 1.9) \times 10^{-4}$$

BES III →

$$x_D = (xx \pm 4.2) \times 10^{-4}$$
$$y_D = (xx \pm 1.7) \times 10^{-4}$$

SuperD →

$$x_D = (xx \pm 2.0) \times 10^{-4}$$
$$y_D = (xx \pm 1.2) \times 10^{-4}$$

Uncertainty in x_D improves more than that of y_D

Extend to Other Channels
Use Quantum-Correlations (QC)

- Running at ψ(3770) CLEO c were able to measure $K^-\pi^+$ strong phase:

  $$\cos\delta_{K\pi} = 1.03^{+0.31}_{-0.17} \pm 0.06$$

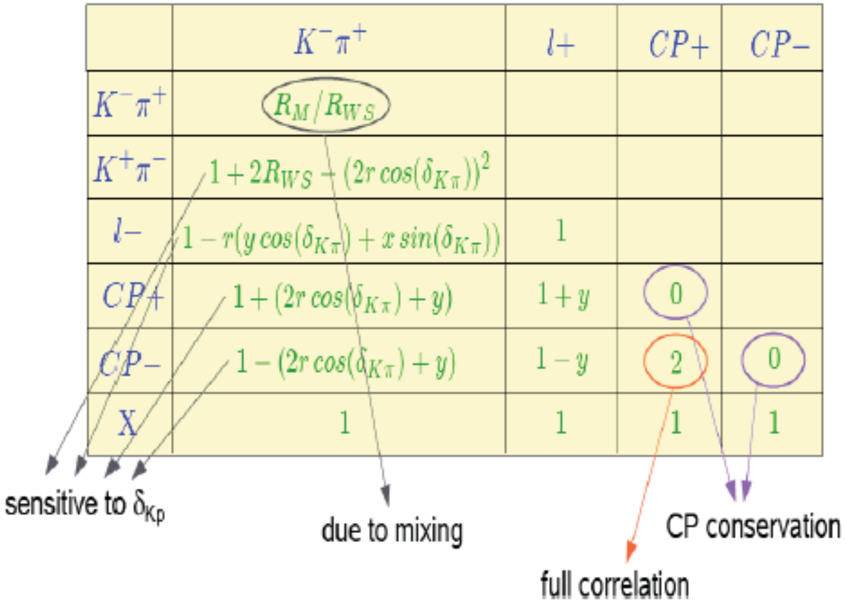
  from 281 pb^{-1}

  Main systematic uncertainty comes from π^0 and η efficiency.

- Including other D mixing results:

  $$\delta_{K\pi} = 22^{+11}_{-12}\,{}^{+9}_{-11}$$

Correlated D^0 decay rate divided by the incoherent decay rate



	$K^-\pi^+$	$l+$	$CP+$	$CP-$
$K^-\pi^+$	R_M/R_{WS}			
$K^+\pi^-$	$1+2R_{WS}-(2r\cos(\delta_{K\pi}))^2$			
$l-$	$1-r(y\cos(\delta_{K\pi})+x\sin(\delta_{K\pi}))$	1		
$CP+$	$1+(2r\cos(\delta_{K\pi})+y)$	$1+y$	0	
$CP-$	$1-(2r\cos(\delta_{K\pi})+y)$	$1-y$	2	0
X	1	1	1	1

sensitive to δ_{Kp}

due to mixing

CP conservation

full correlation

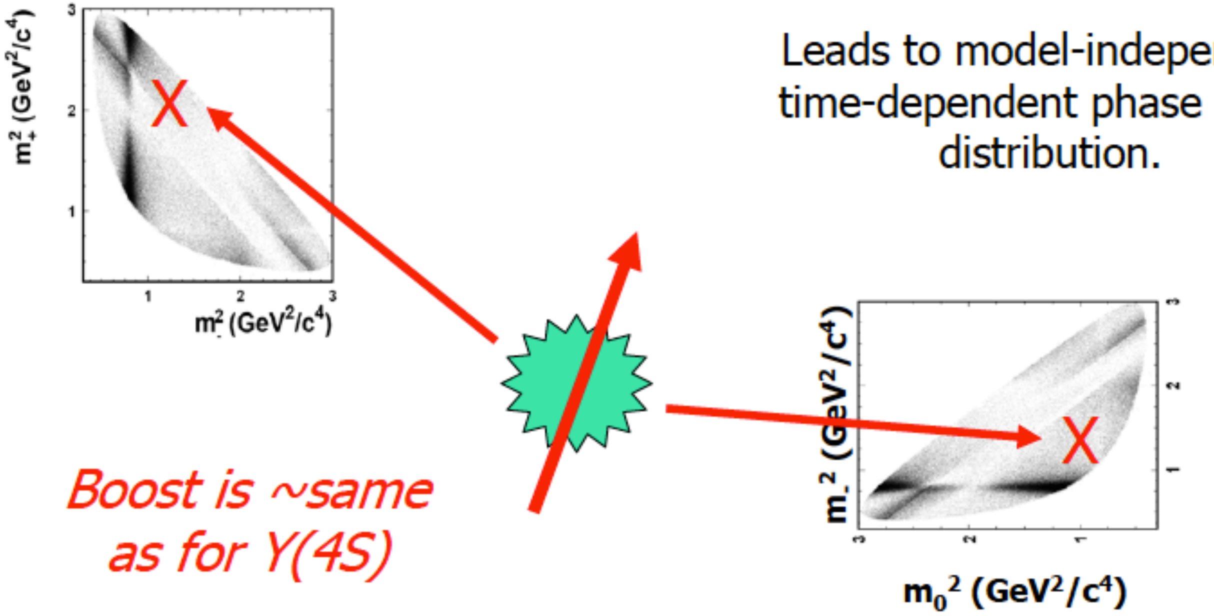
→ SuperB 300 fb^{-1}:

$$\begin{aligned}\sigma(\cos\delta_{K\pi}) &\sim \pm(0.01\rightarrow 0.02)\\ \sigma(\delta_{K\pi}) &\sim \pm(1\rightarrow 2)^\circ\end{aligned}$$

AND – the possibilities are that we can use OTHER channels with knowledge of strong phases

Time-dependent QC Decays – "Super D"?

- The moving CMS means we could measure time-dependent (TD) strong phases resulting from D^0 mixing.



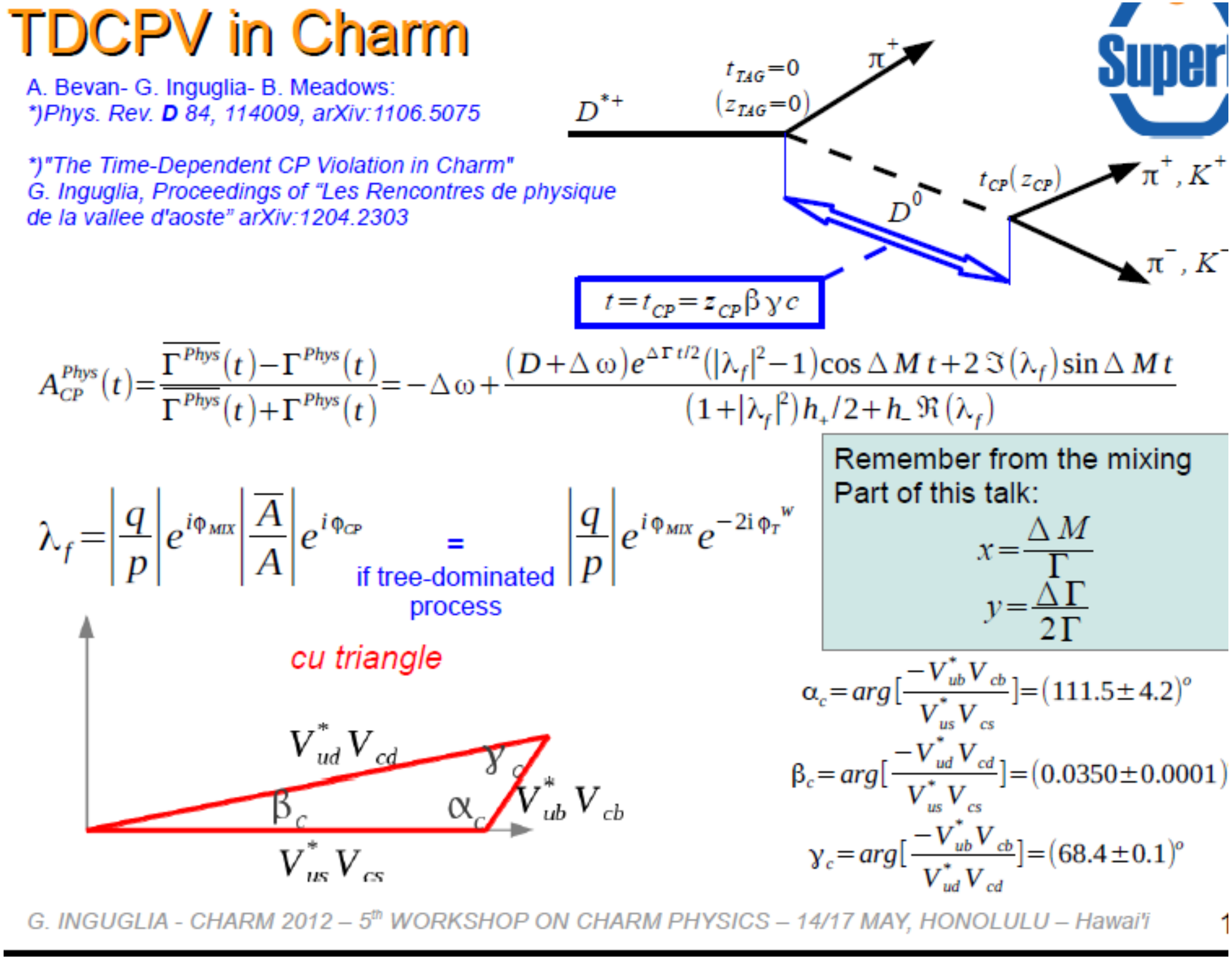
Leads to model-independent time-dependent phase space distribution.

Boost is ~same as for Y(4S)

Is this <u>possible</u> or <u>useful</u> ?

Time-Dependent Charm

- Time-dependence of double tagged events: mixing/CPV
- More "conventional" CPV analysis approach
- If you want to do TD measurements in charm you will need a vertex detector (and a boost).
  - Want a low mass tracking device – is that compatible with strip detectors? If not what about MAPS?
  - To be discussed in the SVT parallel session this afternoon.
  - Also see talk by Inguglia in the physics parallel session tomorrow.



TDCPV in Charm

A. Bevan- G. Inguglia- B. Meadows:
*)Phys. Rev. **D** 84, 114009, arXiv:1106.5075

*)"The Time-Dependent CP Violation in Charm"
G. Inguglia, Proceedings of "Les Rencontres de physique de la vallee d'aoste" arXiv:1204.2303

$$A_{CP}^{Phys}(t)=\frac{\overline{\Gamma}^{Phys}(t)-\Gamma^{Phys}(t)}{\overline{\Gamma}^{Phys}(t)+\Gamma^{Phys}(t)}=-\Delta\omega+\frac{(D+\Delta\omega)e^{\Delta\Gamma t/2}(|\lambda_f|^2-1)\cos\Delta M t+2\Im(\lambda_f)\sin\Delta M t}{(1+|\lambda_f|^2)h_+/2+h_-\Re(\lambda_f)}$$

$$\lambda_f=\left|\frac{q}{p}\right|e^{i\phi_{MIX}}\left|\frac{\overline{A}}{A}\right|e^{i\phi_{CP}} = \left|\frac{q}{p}\right|e^{i\phi_{MIX}}e^{-2i\phi_T^W}$$

= if tree-dominated process

Remember from the mixing Part of this talk:

$$x=\frac{\Delta M}{\Gamma}$$
$$y=\frac{\Delta\Gamma}{2\Gamma}$$

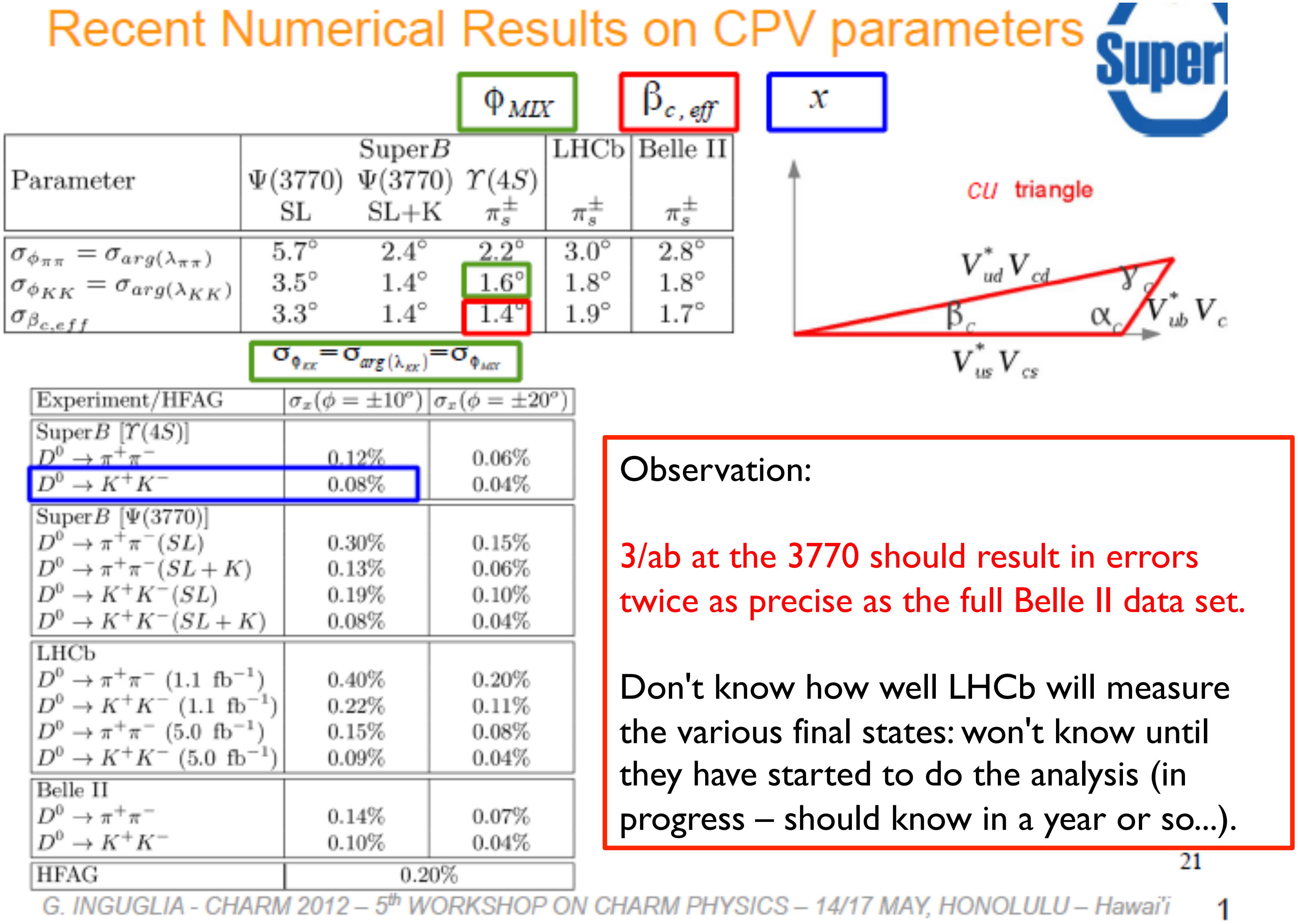
cu triangle

$$\alpha_c=arg[\frac{-V_{ub}^*V_{cb}}{V_{us}^*V_{cs}}]=(111.5\pm4.2)^o$$

$$\beta_c=arg[\frac{-V_{ud}^*V_{cd}}{V_{us}^*V_{cs}}]=(0.0350\pm0.0001)$$

$$\gamma_c=arg[\frac{-V_{ub}^*V_{cb}}{V_{ud}^*V_{cd}}]=(68.4\pm0.1)^o$$

See also Meadows @ Charm WS 2011



Recent Numerical Results on CPV parameters

ϕ_{MIX} $\beta_{c,eff}$ x

Parameter	SuperB $\Psi(3770)$ SL	 $\Psi(3770)$ SL+K	 $\Upsilon(4S)$ $\pi_s^\pm$	LHCb $\pi_s^\pm$	Belle II $\pi_s^\pm$
$\sigma_{\phi_{\pi\pi}} = \sigma_{arg(\lambda_{\pi\pi})}$	5.7°	2.4°	2.2°	3.0°	2.8°
$\sigma_{\phi_{KK}} = \sigma_{arg(\lambda_{KK})}$	3.5°	1.4°	1.6°	1.8°	1.8°
$\sigma_{\beta_{c,eff}}$	3.3°	1.4°	1.4°	1.9°	1.7°

$\sigma_{\phi_{KK}} = \sigma_{arg(\lambda_{KK})} = \sigma_{\phi_{MIX}}$

Experiment/HFAG	$\sigma_x(\phi = \pm 10^o)$	$\sigma_x(\phi = \pm 20^o)$
Super$B$ [$\Upsilon(4S)$]		
$D^0 \to \pi^+\pi^-$	0.12%	0.06%
$D^0 \to K^+K^-$	0.08%	0.04%
Super$B$ [$\Psi(3770)$]		
$D^0 \to \pi^+\pi^-(SL)$	0.30%	0.15%
$D^0 \to \pi^+\pi^-(SL+K)$	0.13%	0.06%
$D^0 \to K^+K^-(SL)$	0.19%	0.10%
$D^0 \to K^+K^-(SL+K)$	0.08%	0.04%
LHCb		
$D^0 \to \pi^+\pi^-$ (1.1 fb^{-1})	0.40%	0.20%
$D^0 \to K^+K^-$ (1.1 fb^{-1})	0.22%	0.11%
$D^0 \to \pi^+\pi^-$ (5.0 fb^{-1})	0.15%	0.08%
$D^0 \to K^+K^-$ (5.0 fb^{-1})	0.09%	0.04%
Belle II		
$D^0 \to \pi^+\pi^-$	0.14%	0.07%
$D^0 \to K^+K^-$	0.10%	0.04%
HFAG	0.20%	

Observation:

3/ab at the 3770 should result in errors twice as precise as the full Belle II data set.

Don't know how well LHCb will measure the various final states: won't know until they have started to do the analysis (in progress – should know in a year or so...).

21

G. INGUGLIA - CHARM 2012 – 5th WORKSHOP ON CHARM PHYSICS – 14/17 MAY, HONOLULU – Hawai'i 1

See also Meadows @ Charm WS 2011

Sensitivity studies: overview

- For ψ(3770) modes
  - Extrapolate CLEOc yields (includes cross-sections and selection efficiencies)
  - Correct by SuperB geometrical efficiency vs CM boost
  - Evaluate triple Gaussian (TG) resolution function from FastSim vs CM boost
- For ϒ(4S) modes, extrapolate BaBar yields
  - TG proper time resolution of ~0.15 ps (0.1 ps core)
- Toy MC generator and fitter developed
  - For now focus on 2-body decays
  - the next step will be 3-body decays

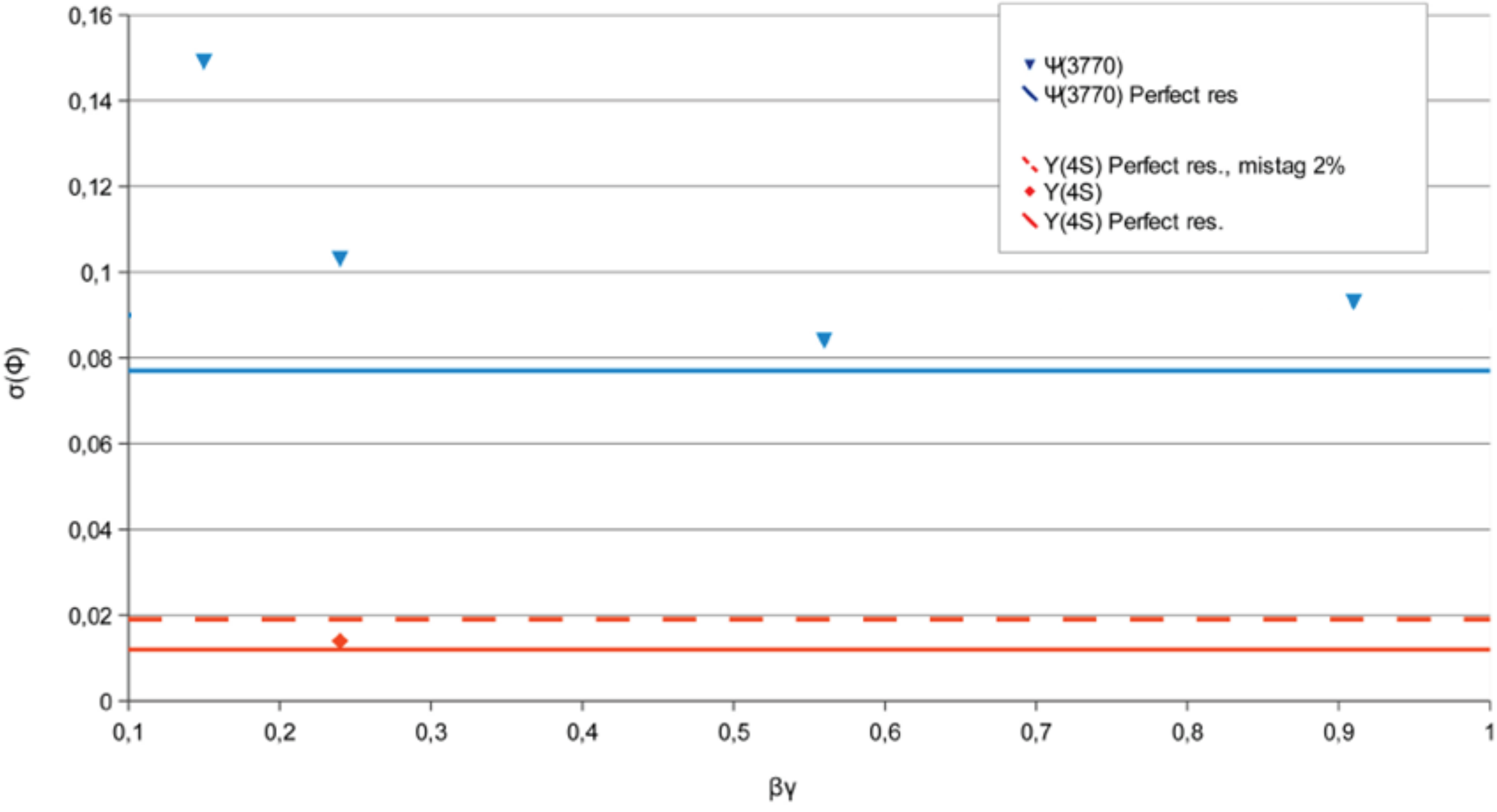
Double tags @ Ψ(3770)
Modes with D* tag @ ϒ(4S)
used in this study

	CP–	Kπ	lX
CP+	X	X	XX
CP–		X	XX
Kπ		X	XX
lX			XX

simulated datasets:
75 ab^{-1} at Y(4S)
0.5 ab^{-1} at Ψ(3770)

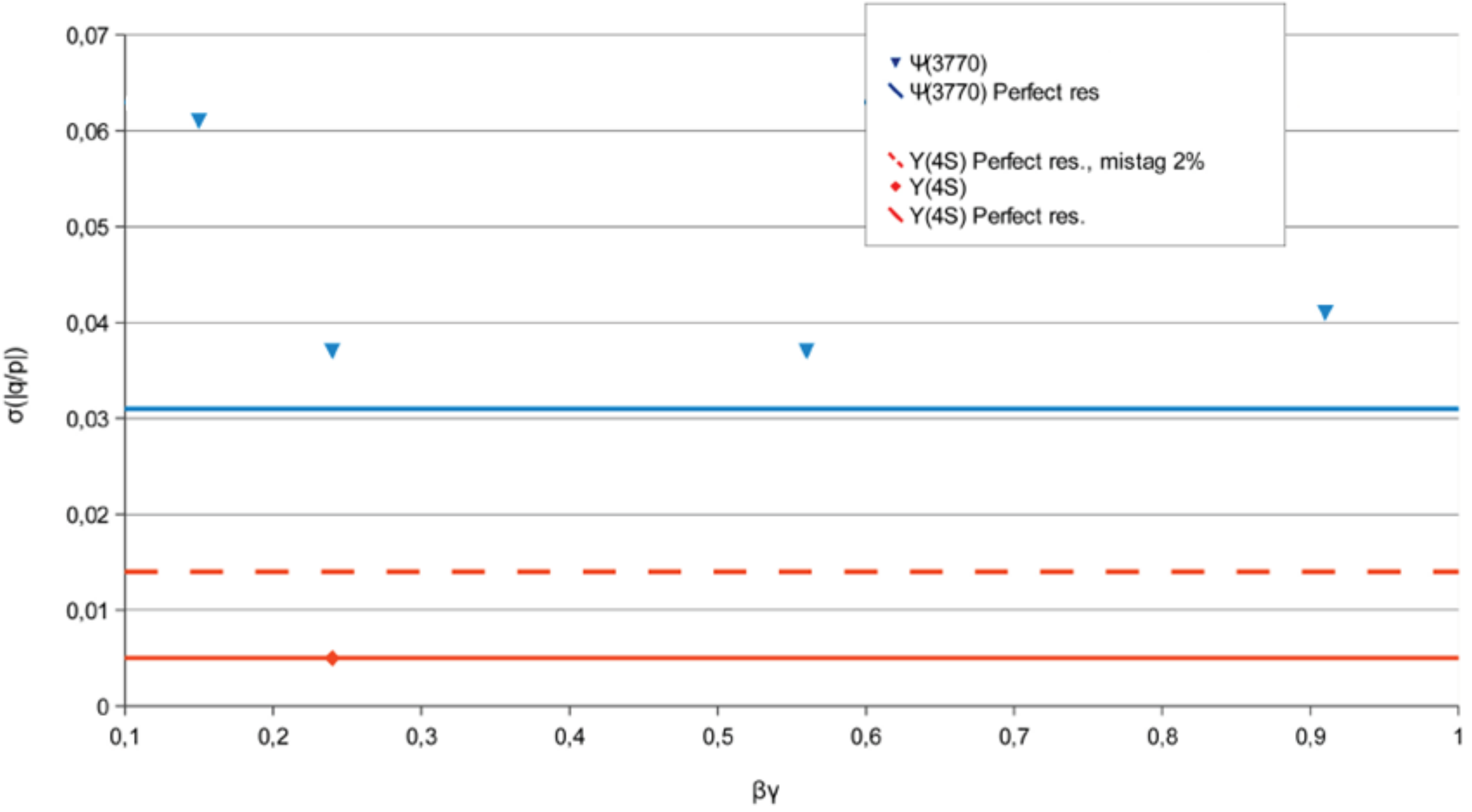
Neri et al

Sensitivity: ϕ=arg(q/p)



- Neri et al

Sensitivity: |q/p|



Neri et al

Summary: time-dependent studies for mixing

- Flavor tag at $D\bar{D}$ threshold provides identical time-dependence than at $\Upsilon(4S)$ using D* tagging, and less events, although in a different environment
- $D\bar{D}$ threshold is unique to provide CP, $K\pi$ and $Ks\pi\pi$ tags
- Variation of Δt resolution and geometrical acceptance vs CM boost was evaluated
- Estimated the impact on physics with 2-body decays

➢Combined fit to all 2-body double-tags allows determination of x, y, arg(q/p), |q/p|

➢Best sensitivity at $\Psi(3770)$ for intermediate boost, $\beta\gamma\sim0.3\text{-}0.6$

Parameter	Sensitivity @ $\Upsilon(4S)$ with time resolution, no mistag. 75 ab^{-1}	Best sensitivity @ $\psi(3770)$ with time resolution ($\beta\gamma=0.56$), no mistag. 0.5 ab^{-1}
x	0.017%	0.11%
y	0.008%	0.05%
Arg(q/p)	0.8 deg	4.8 deg
|q/p|	0.5%	3.7%

Relative effect of flavor mistag similar at $\Psi(3770)$ and $\Upsilon(4S)$

➢error per ab^{-1} at $\Psi(3770)$ ~ ½ error per ab^{-1} at $\Upsilon(4S)$ (2-body only, no mistag)

➢error at $\Psi(3770)$ [0.5ab^{-1}] ~ 6x error at $\Upsilon(4S)$ [75ab^{-1}] (2-body only, no mistag)

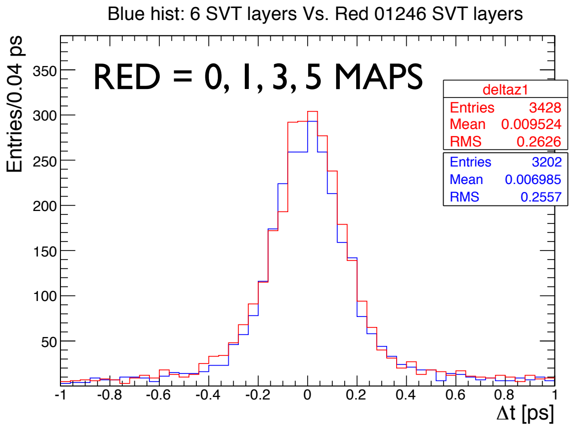
Neri et al

FastSim Studies

(Gianluca Inguglia, QMUL)

- Baseline SVT vs 4 Layers of INMAPS

$$D^0 \rightarrow h^+h^-$$



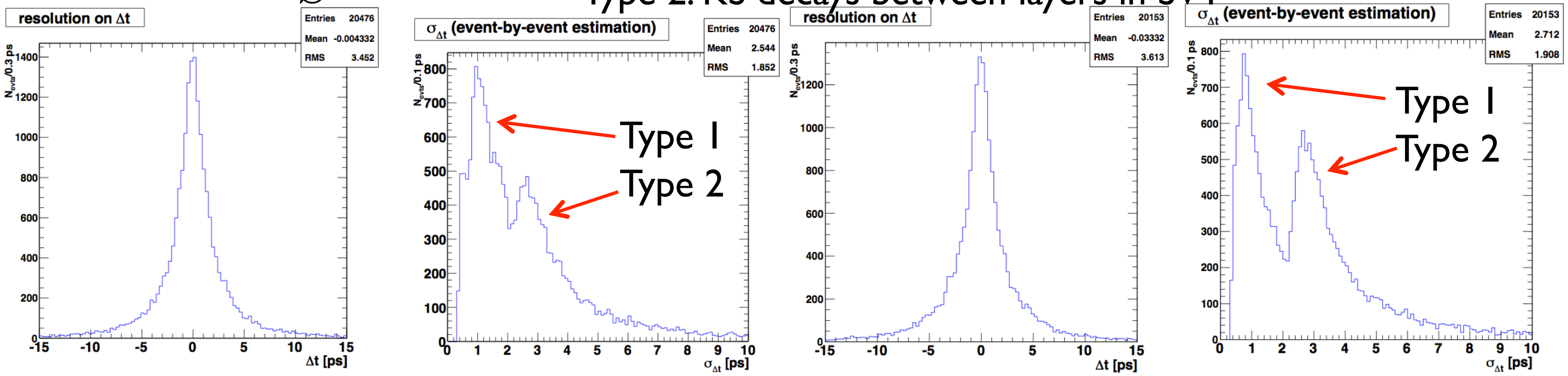
Initial studies suggest it is possible to do TDCPV measurements with a 4 layer MAPS SVT.

→Optimise X_0 of SVT for CT. Discussion starts this afternoon.

$$D^0 \rightarrow K_S^0\pi^0$$

Type 1: KS decays in beam pipe

Type 2: KS decays between layers in SVT



- Large RMS from Type 2 events

(Alex Hahn, Mainz/QMUL)

Time-Dependent Charm

- Optimal boost (for the 4S detector ~0.55)
- Note that there is a boost factor vs polarisation correlation
- Both studies agree that these measurements should be possible
- Note: a lot of different final states to do TDCPV measurements in: some work: $D^0 \rightarrow h^+h^-$ and $K_S\pi^0$ under study with FastSim (see Inguglia tomorrow).
  - These measurements are possible for a tau-charm experiment.
- Related final states will be required to control hadronic uncertainties: we need these to interpret results in terms of the SM.

Selection of interesting measurements at a few ab^{-1} run at/near charm threshold

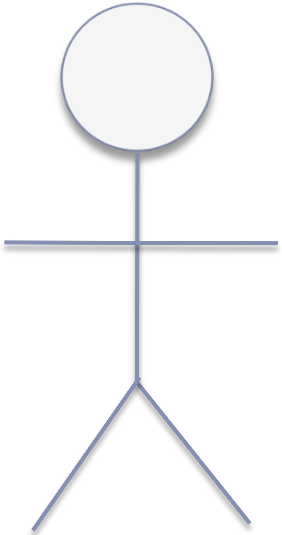
Decay mode	Expected precision
$D^0 \to \mu^+\mu^-, e^+e^-, e^+\mu^-, \ldots$	few 10^{-9} at 90% C.L.
$D^+ \to \pi^+ \nu\nu$, $D^0 \to K^0 \nu\nu$, $D_s^+ \to \pi^+ \nu\nu$	TBD
A_{CP} in $D^0 \to \pi^+ \pi^0$	10^{-3}
A_{CP} in $D \to V \gamma$	10^{-3}
cos (delta_kpi) and other strong phases [they improve measurements of UT gamma and D mixing]	1 deg
$D^0 \to X l^+l^-$ (BF vs $M(l^+l^-)$)	TBD
a_{SL}	15%

Interesting but limited in theoretical interpretation

$\sin(2\beta_c\_eff)$	2 deg
$D^0 \to \gamma\gamma$	10^{-8} (~SM value)

Seems not competitive with other experiments or theory/syst. dominates at few ab^{-1}

- x, y and CPV in mixing
- $f(D^+)$, $f(D_s)$



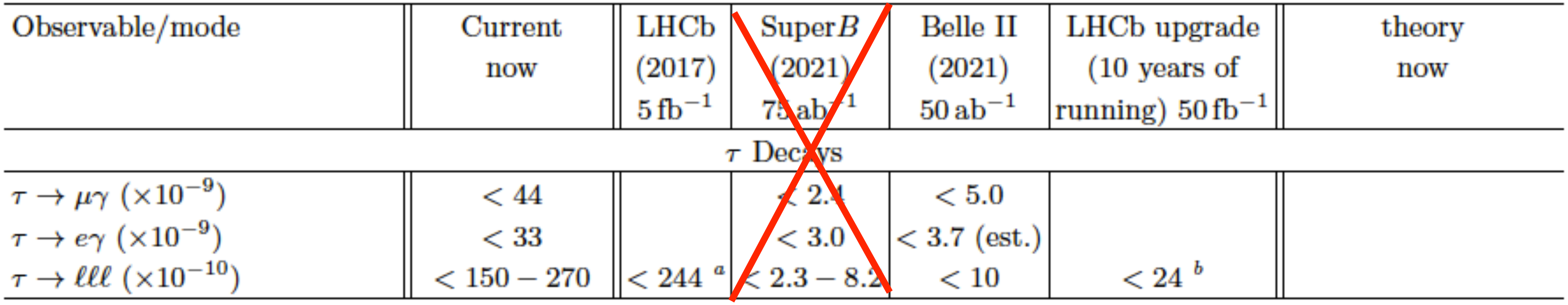
Tau

LFV, CPV, Precision

LFV The competition

- Belle II expect to record 50/ab circa 2020/2021.
  - Can estimate tau sensitivity from their/our 4S physics programme:

- LHCb have started to search for 3 track final states:
  - Not clear how this evolves as current analysis has some background.
  - Claims that this scales with luminosity are unclear... but the trigger will be improved at LHCb, and they will get 5 times more data.
  - Then there is the LHCb upgrade that will be relevant on the timescales of a SuperτC.



Observable/mode	Current now	LHCb (2017) 5 fb^{-1}	~~Super$B$ (2021) 75 ab^{-1}~~	Belle II (2021) 50 ab^{-1}	LHCb upgrade (10 years of running) 50 fb^{-1}	theory now
			τ Decays			
$\tau \to \mu\gamma$ $(\times 10^{-9})$	< 44		~~< 2.4~~	< 5.0		
$\tau \to e\gamma$ $(\times 10^{-9})$	< 33		~~< 3.0~~	< 3.7 (est.)		
$\tau \to \ell\ell\ell$ $(\times 10^{-10})$	$< 150 - 270$	< 244 [a]	~~$< 2.3 - 8.2$~~	< 10	< 24 [b]	

$\tau \to \mu\gamma$ at $\tau{-}c$ factory

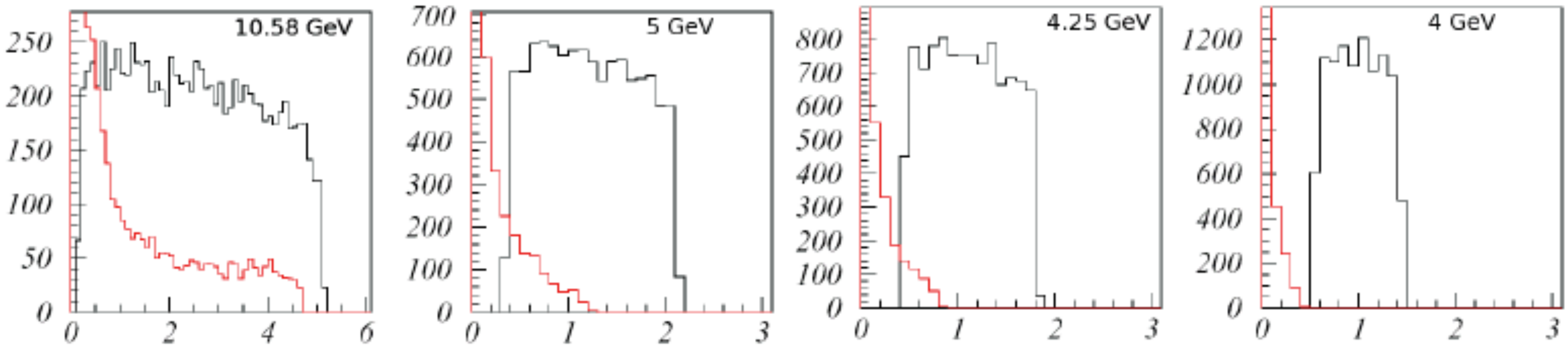
Should clarify which end of 10^{-9} this range sits at!

- BR expected 90% CL upper limit for SuperB with $75\,\mathrm{ab}^{-1} = 2.4 \cdot 10^{-9}$
  (SuperB physics reports)
- BR sensitivity of $\tau{-}c$ factory with $7\,\mathrm{ab}^{-1} \approx 10^{-9}$
  A.V.Bobrov, A.E.Bondar, Search for $\tau \to \mu\gamma$ decay at Super $c{-}\tau$ factory, Nucl.Phys.B (Proc.Suppl.) 225 (2012), arXiv:1206.1909 [hep-ex], (PHIPSI 2011 proceegings)
  - Monte Carlo simulation of expected backgrounds
  - less bkg from ISR than at $\Upsilon(4S)$ (see next slide)
- beam polarization provides additional benefits in sensitivity and New Physics models testing

A SES of a few ×10^{-9} would be an interesting target for LFV if one could perform the measurement on a sensible timescale.

ISR bkg to $\tau \to \mu\gamma$ reduced at τ–c factory

- $\tau \to \mu\gamma$ background from ISR photon + SM $\tau \to \mu\nu\overline{\nu}$ decay
- at $\tau - c$ factory, ISR photon has lower energy than the photon from $\tau \to \mu\gamma$
  - H.Hayashii, "Search for $\tau \to \mu/e\gamma$ at the Super-τ-charm Factory", Tau 2008 Workshop Satellite meeting on the Super τ-charm factory



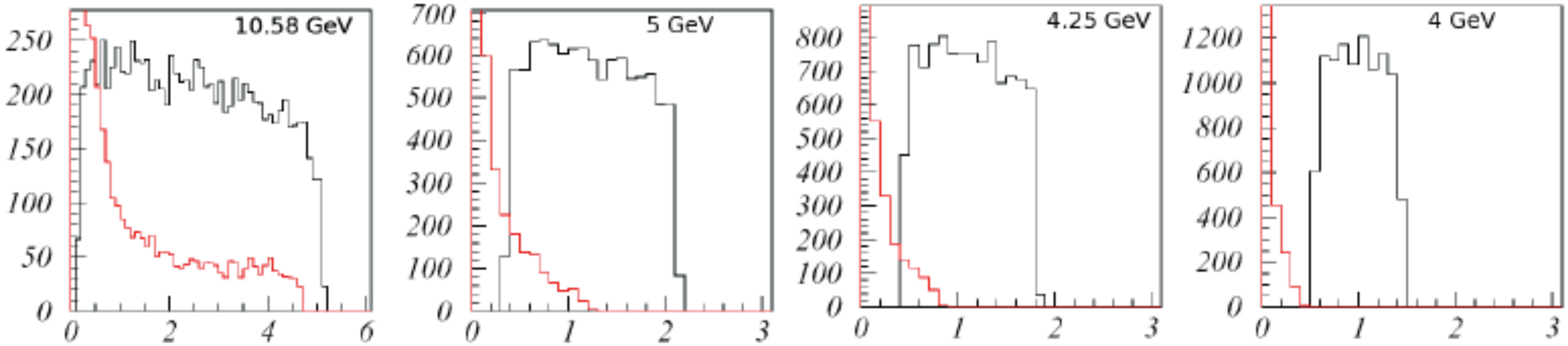
Clean

Irreducible background

Cleaner

ISR bkg to $\tau \to \mu\gamma$ reduced at $\tau{-}c$ factory

- $\tau \to \mu\gamma$ background from ISR photon + SM $\tau \to \mu\nu\overline{\nu}$ decay
- at $\tau - c$ factory, ISR photon has lower energy than the photon from $\tau \to \mu\gamma$
  - H.Hayashii, “Search for $\tau \to \mu/e\gamma$ at the Super-τ-charm Factory”, Tau 2008 Workshop Satellite meeting on the Super τ-charm factory



Q) With such a clean signature for low energy – is there any gain from polarisation?

Other Tau Physics topics at a $\tau-c$ factory

- references:
    - Physics at BES-III, J. of Modern Physics A24.1 supp (2009), arXiv:0809.1869 [hep-ex]
    - "A PROJECT OF SUPER $c-\tau$ FACTORY IN NOVOSIBIRSK", Conceptual Design Report, 2011, Budker, Novosibirsk
- improve lepton universality tests (tau mass and leptonic BRs)
- close to threshold, it is possible to tag a single tau hadronic decay with $2m_\tau E_{\text{had}} = m_\tau^2 + m_{\text{had}}^2$
- measuring hadronic BRs and spectra one may optain the most precise experimental measurements of α_s, V_{us} and m_s
- study of the Lorentz structure of the leptonic decays (EW test)
- CPV in tau decay (both rate asymmetry and angle differential asymmetry)

CPV

- 2 routes to CP violation in tau programme:

- tau EDM
  - low lumi measurement by Belle from

- CPV in decay
  - Recent results from Belle and BaBar in $\tau \to K_S^0 \pi \nu$

- Ideally would be useful to have some studies in this area.

- Should investigate the benefit of polarisation here.

Thanks to Mike and Hayashii-san: see the Physics of the B Factories Book, section 20.5

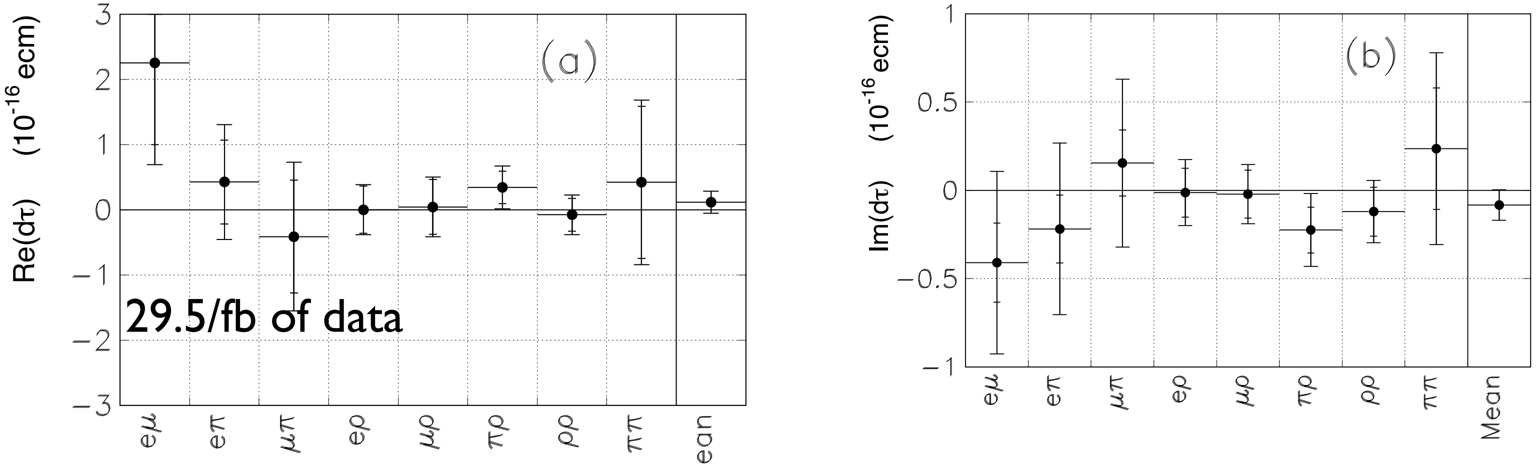
Tau EDM

- Introduce a CP violating term in the effective Hamiltonian:

$$H = -d\boldsymbol{E} \cdot \frac{\boldsymbol{S}}{S}.$$

- Look for the interference term

$$\mathcal{M}^2 = \mathcal{M}^2_{\rm SM} + \boxed{Re(d^{\gamma}_{\tau})\mathcal{M}_{Re} + Im(d^{\gamma}_{\tau})\mathcal{M}_{Im}} + |d_\tau|^2\mathcal{M}^2_{d^2},$$



29.5/fb of data

Is threshold competitive with 4S running?

K. Inami et al., Phys. Lett. B551, 16–26 (20031)68.5
hep-ex/0210066.

Tau CPV in decay

- In the SM CPV in tau decay is absent; modulo quark CPV in final states with kaons.
- BaBar looks for a time integrated asymmetry in the full data set:

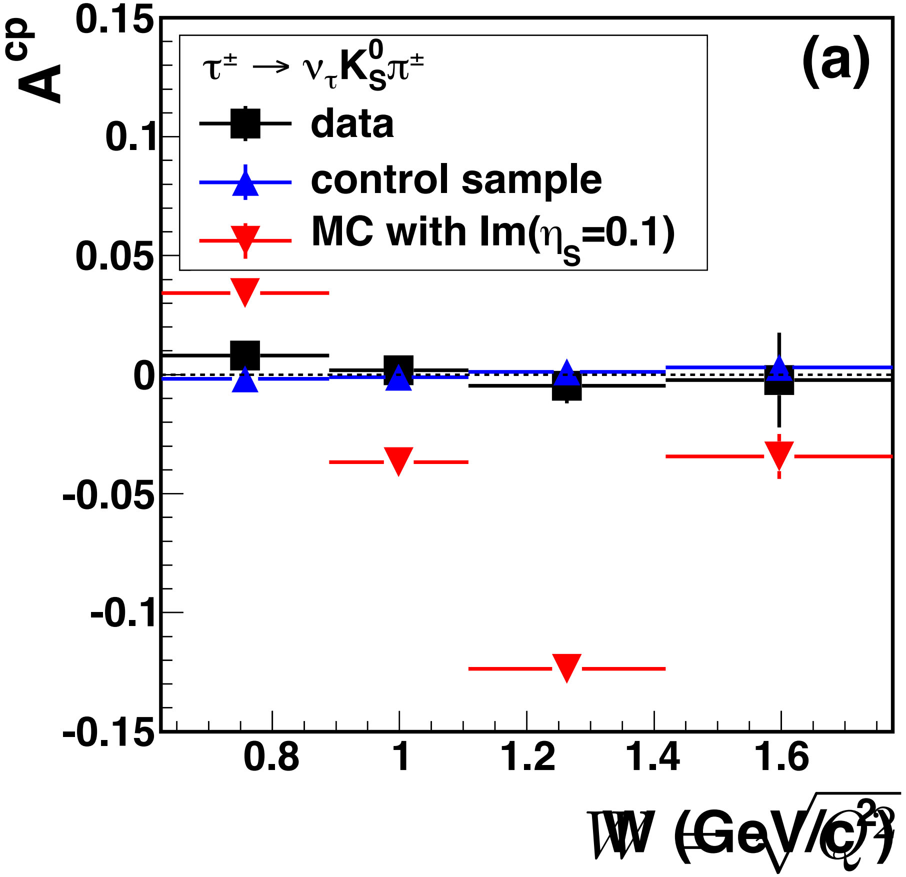
$$A_{CP} = \frac{\Gamma(\tau^+ \to K_S^0 \pi^+ \nu_\tau) - \Gamma(\tau^- \to K_S^0 \pi^- \nu_\tau)}{\Gamma(\tau^+ \to K_S^0 \pi^+ \nu_\tau) + \Gamma(\tau^- \to K_S^0 \pi^- \nu_\tau)}$$

- Finds a −0.36% asymmetry – compatible with the SM at 2.8σ
- Some new physics models have subtle effects that are integrated over in the above asymmetry... can look at helicity angle distributions to extract more information.

Thanks to Mike and Hayashii-san: see the Physics of the B Factories Book, section 20.5

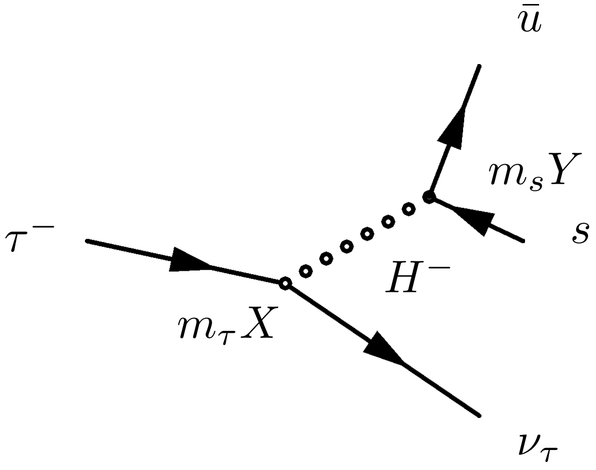
Tau CPV in decay

- Skipping the details [see PRL 107, 131801 (2011)]
- Result obtained is compatible with SM.



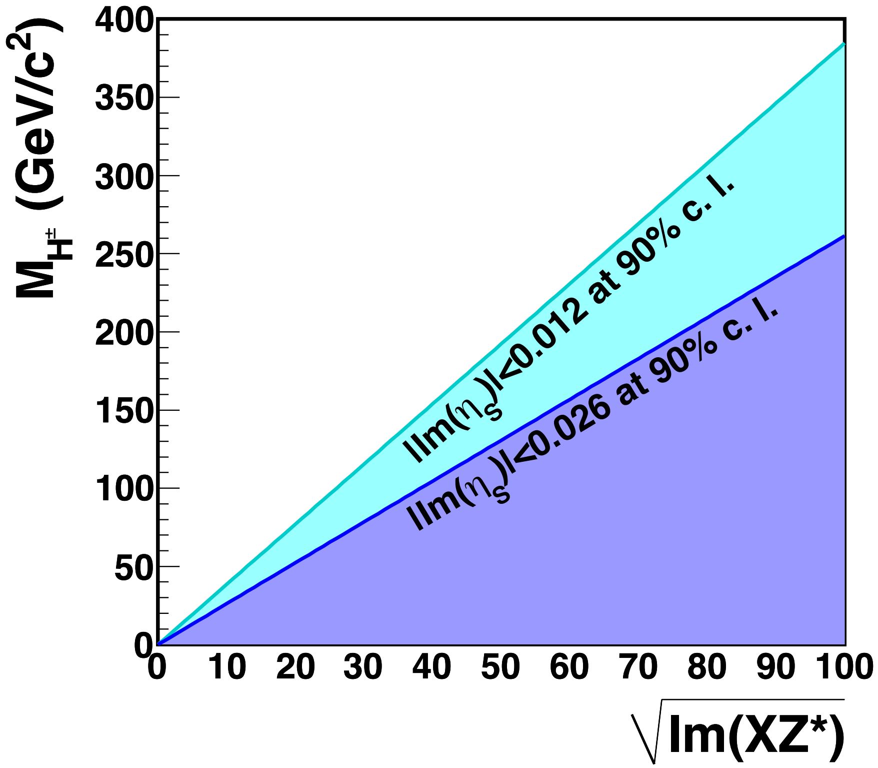
Tau CPV in decay

- Skipping the details [see PRL 107, 131801 (2011)]
- Result obtained is compatible with SM – but can be related to the charged Higgs sector in MHDM's.



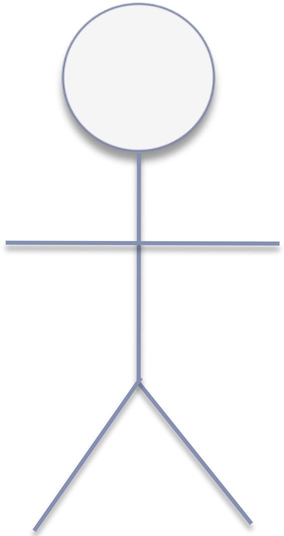
Here X and Z are complex couplings, related to the measured asymmetry via η .

$$\eta_S \simeq \frac{m_\tau m_s}{M^2_{H\pm}} \cdot X^* Z$$



Tau Precision

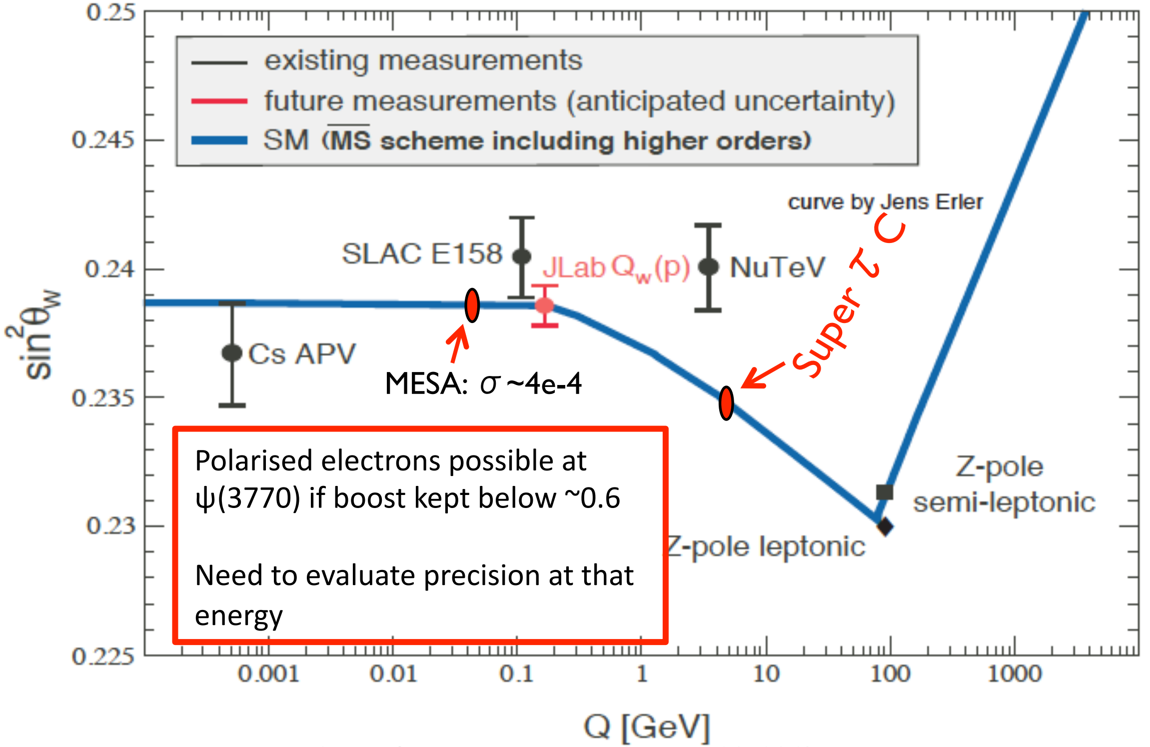
- Many interesting measurements to be made ... a few ideas to look at:
  - Precision measurement of $|V_{us}|$ using tau decays to final states with kaons (theoretically cleaner than the *standard* kaon decay route)
  - Starting points: the physics white paper, Stahl, and the Physics of the B factories book tau chapter (if you are on BaBar or Belle you have access to this, otherwise should be publicly available by end of spring 2013).



Electroweak

precision

- Now that the Higgs has been measured, precision EW tests such as $\sin^2\theta_W$ measurements are NP tests.
- See the talk by Mike Roney in the physics parallel session.

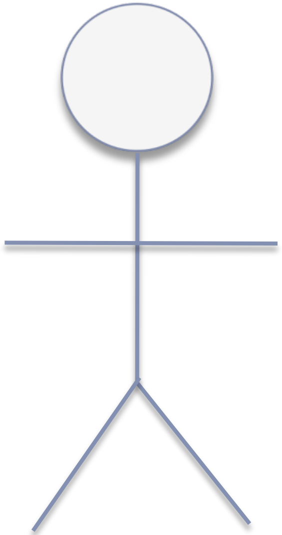


Polarised electrons possible at ψ(3770) if boost kept below ~0.6

Need to evaluate precision at that energy

Plot adapted from QWeak proposal (JLAB E02-020)

$$\cancel{e^+e^- \to b\bar{b}}$$
$$e^+e^- \to c\bar{c}$$
$$e^+e^- \to \tau^+\tau^-$$
$$e^+e^- \to \mu^+\mu^-$$



Spectroscopy

In addition to conventional spectroscopy

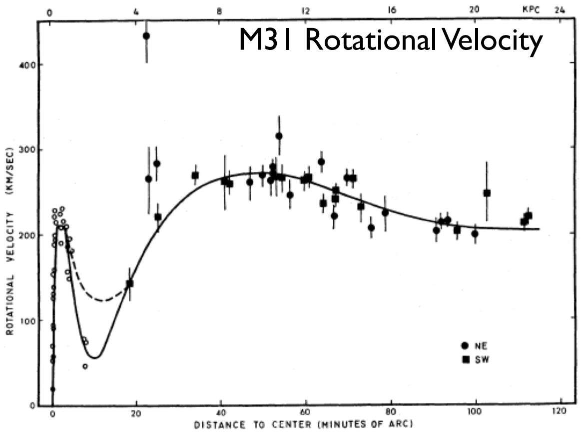
Conventional spectroscopy

- A question to the machine experts:
  - What is the maximum energy that can be reached?
  - Unless we hear otherwise we will assume 4170 (for τ and D_S)+ 10%, so a maximum of 4587 MeV comes for "free" on paper.

- It would be useful to be able to reach 4660 MeV
  - Is this realistic from the machine design point of view?
  - What are the additional RF cost implications for such a target?

Dark Forces?

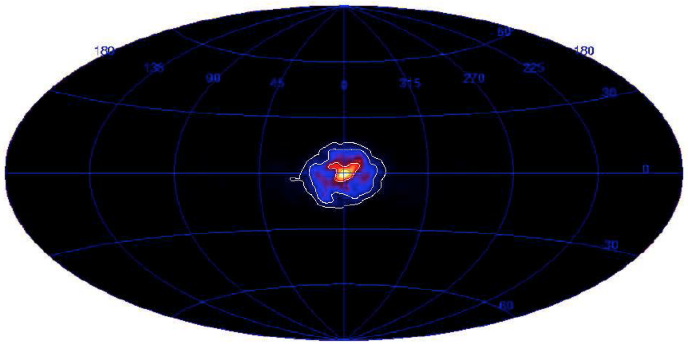
- Overwhelming astrophysical evidence for dark matter with several possibly related anomalies:
  - Rotational velocity of spiral galaxies,
  - Integral's 511 keV γ excess,
  - PAMELA rising e^+ fraction, FERMI, DAMA/LIBRA results,
  - WMAP data ...



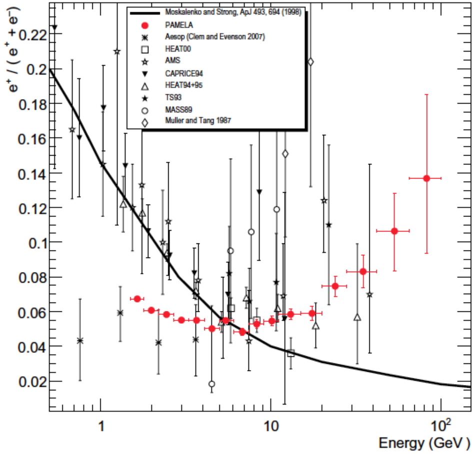
M31 Rotational Velocity

Rubin & Ford, APJ **159** 379-403 (1970)

INTEGRAL, Astron. Astrophys. **441** 513-532 (2005)



Fermi results now much more precise than PAMELA (see ICHEP 2012)



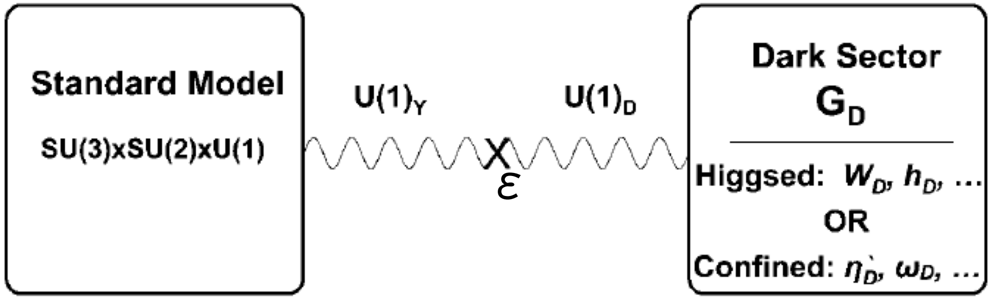
PAMELA, New J. Phys. 11 105023 (2009)

- This motivates ongoing searches for SUSY at the LHC and light scalars and dark sector particles at B Factories.

Dark Forces?

- The need for dark matter is well understood – but this is part of the solution.

e.g. R. Essig et al.
[PRD **80** 015003 (2009)]



MeV – 10 GeV low energy dark sector:

- MeV scale dictated by interpretation of INTEGRAL data:

$$\chi\chi \to e^+e^- \qquad \text{vs.} \qquad \chi\chi \to \chi\chi^* \to \chi\chi e^+e^-$$

- Natural dark sector mass scale of O(GeV) for ~TeV scale DM.

Interaction with SM matter through kinetic mixing ε, and we want to constrain the coupling g_D and/or ε.

- B factories are a good place to look for dark forces: so is KLOE

Dark Forces?

$$e^+e^- \to A'h' \, (h' \to A'A')$$

Accessible final states depend on mass of *A*'

Can search for dark Higgs (*h*') and dark photons (*A*').

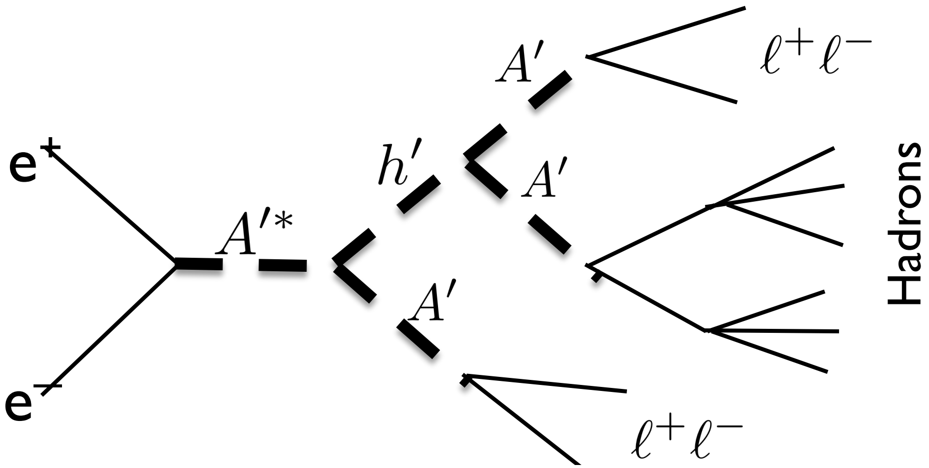
e.g. see: PRL 108, 211801 (2012)

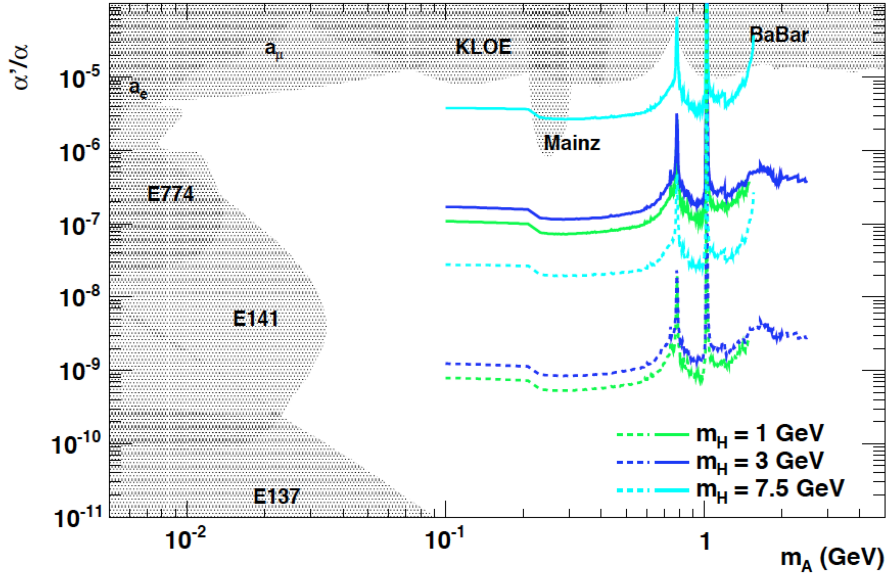
N. Arkani-Hamed et al.
[PRD **79** 015014 (2009)]

B. Batell et al.
[PRD **79** 115008 (2009)]
[PRD **80** 095024 (2009)]

Bjorken et al.
[PRD **80** 075018 (2009)]

R. Essig et al.
[PRD **80** 015003 (2009)]





Bevan, ICHEP 2012

Dark Forces?

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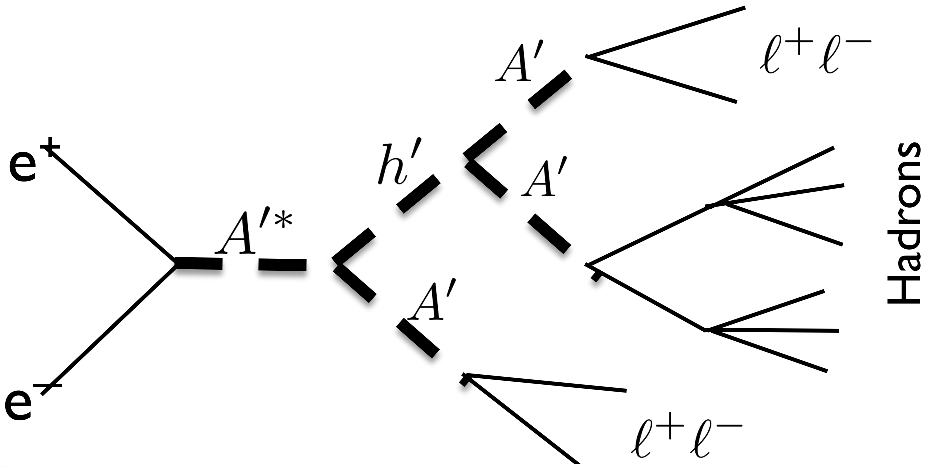
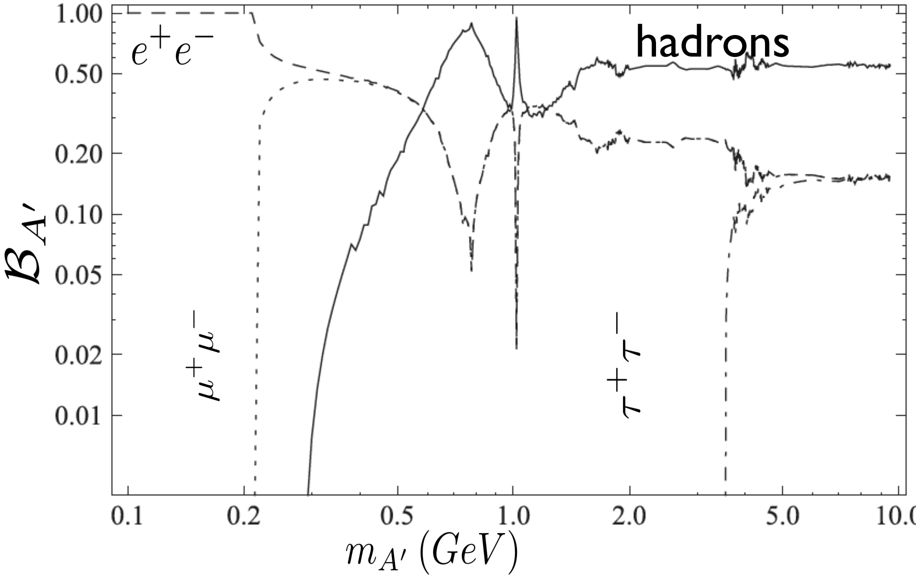
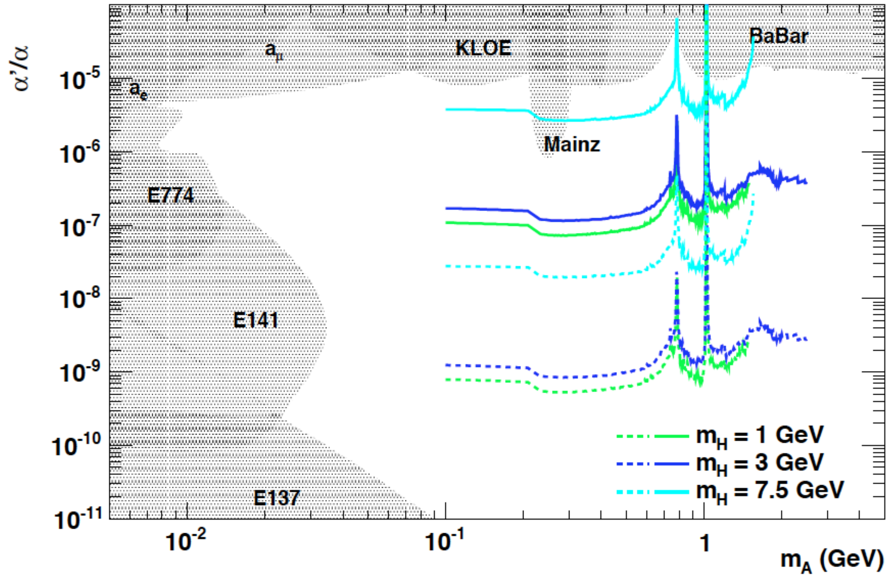




Batell et al., PRD 79 115008 (2008)

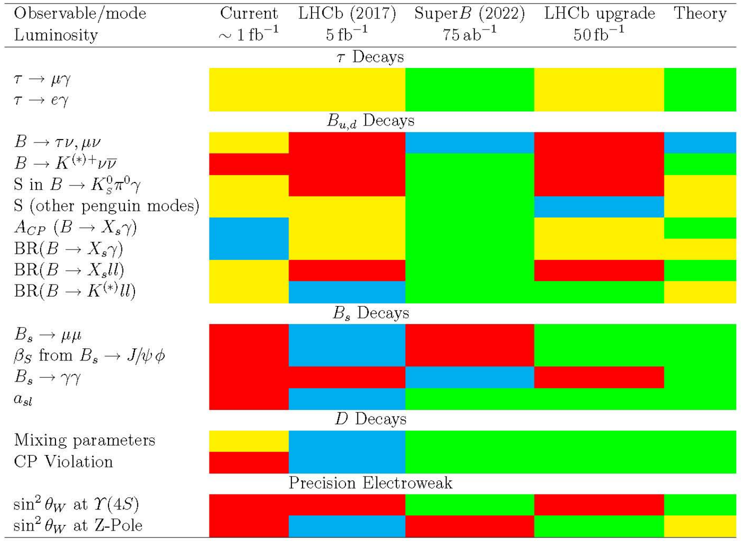


Interplay

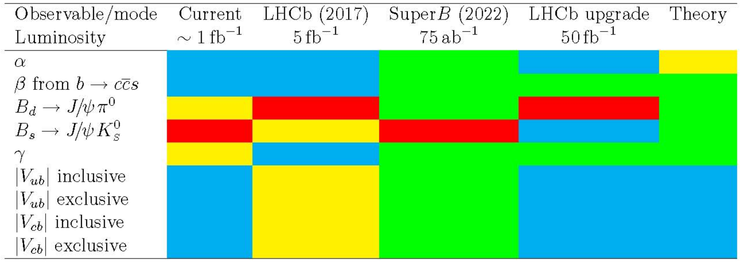
Are the observables playing nicely together? … or is there a new particle on the block?

Interplay

- Many years of effort by theorists and experimentalists went into understanding how to test the SM and decode NP...



Observable/mode Luminosity	Current $\sim 1\,\mathrm{fb}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super$B$ (2022) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory
τ Decays					
$\tau \to \mu\gamma$	🟨	🟨	🟩	🟨	🟩
$\tau \to e\gamma$	🟨	🟨	🟩	🟨	🟩
$B_{u,d}$ Decays					
$B \to \tau\nu, \mu\nu$	🟨	🟥	🟦	🟥	🟦
$B \to K^{(*)+}\nu\overline{\nu}$	🟥	🟥	🟩	🟥	🟩
S in $B \to K_S^0\pi^0\gamma$	🟨	🟥	🟩	🟥	🟨
S (other penguin modes)	🟨	🟨	🟩	🟦	🟨
A_{CP} $(B \to X_s\gamma)$	🟦	🟨	🟩	🟨	🟩
BR$(B \to X_s\gamma)$	🟦	🟨	🟩	🟨	🟨
BR$(B \to X_s ll)$	🟨	🟥	🟩	🟥	🟩
BR$(B \to K^{(*)} ll)$	🟨	🟦	🟩	🟩	🟨
B_s Decays					
$B_s \to \mu\mu$	🟥	🟦	🟥	🟩	🟩
β_S from $B_s \to J/\psi\,\phi$	🟥	🟦	🟥	🟩	🟩
$B_s \to \gamma\gamma$	🟥	🟥	🟦	🟥	🟩
a_{sl}	🟥	🟦	🟩	🟩	🟩
D Decays					
Mixing parameters	🟨	🟦	🟩	🟩	🟩
CP Violation	🟥	🟦	🟩	🟩	🟩
Precision Electroweak					
$\sin^2\theta_W$ at $\Upsilon(4S)$	🟥	🟥	🟩	🟥	🟩
$\sin^2\theta_W$ at Z-Pole	🟥	🟦	🟥	🟩	🟨

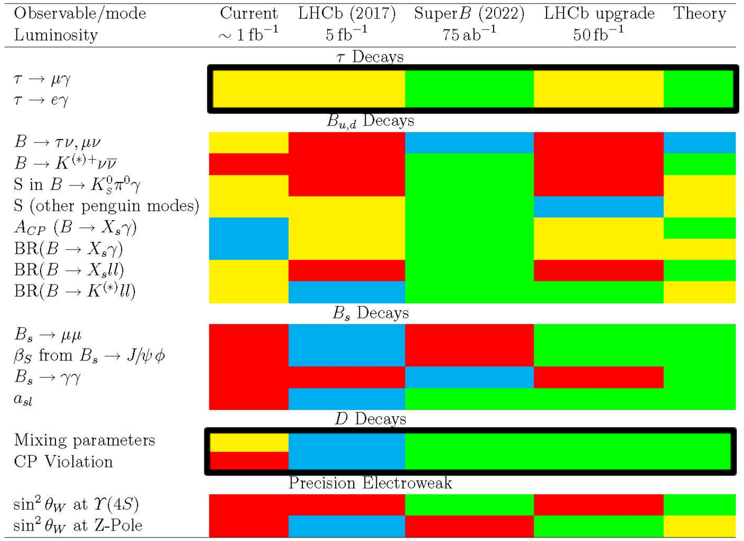


Observable/mode Luminosity	Current $\sim 1\,\mathrm{fb}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super$B$ (2022) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory
α	🟦	🟦	🟩	🟦	🟨
β from $b \to c\overline{c}s$	🟦	🟦	🟩	🟩	🟩
$B_d \to J/\psi\,\pi^0$	🟨	🟥	🟩	🟥	🟩
$B_s \to J/\psi\,K_S^0$	🟥	🟨	🟥	🟦	🟩
γ	🟨	🟦	🟩	🟩	🟩
$\|V_{ub}\|$ inclusive	🟦	🟨	🟩	🟦	🟦
$\|V_{ub}\|$ exclusive	🟦	🟨	🟩	🟦	🟦
$\|V_{cb}\|$ inclusive	🟦	🟨	🟩	🟦	🟦
$\|V_{cb}\|$ exclusive	🟦	🟨	🟩	🟦	🟦

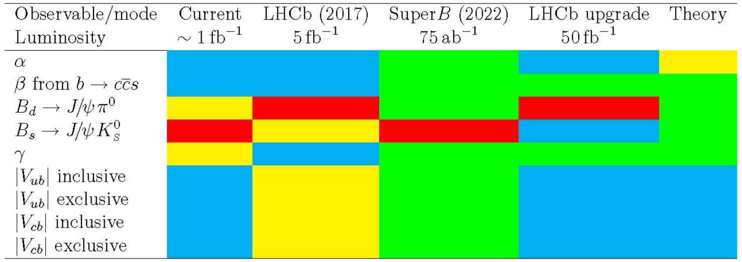
????

Interplay

- Many years of effort by theorists and experimentalists went into understanding how to test the SM and decode NP...



Observable/mode Luminosity	Current $\sim 1\,\mathrm{fb}^{-1}$	LHCb (2017) $5\,\mathrm{fb}^{-1}$	Super$B$ (2022) $75\,\mathrm{ab}^{-1}$	LHCb upgrade $50\,\mathrm{fb}^{-1}$	Theory
τ Decays					
$\tau \to \mu\gamma$	🟨	🟨	🟩	🟨	🟩
$\tau \to e\gamma$	🟨	🟨	🟩	🟨	🟩
$B_{u,d}$ Decays					
$B \to \tau\nu, \mu\nu$	🟨	🟥	🟦	🟥	🟦
$B \to K^{(*)+}\nu\overline{\nu}$	🟥	🟥	🟩	🟥	🟩
S in $B \to K_S^0\pi^0\gamma$	🟨	🟥	🟩	🟥	🟨
S (other penguin modes)	🟨	🟨	🟩	🟦	🟨
A_{CP} $(B \to X_s\gamma)$	🟦	🟨	🟩	🟨	🟩
BR$(B \to X_s\gamma)$	🟦	🟨	🟩	🟨	🟨
BR$(B \to X_s ll)$	🟨	🟥	🟩	🟥	🟩
BR$(B \to K^{(*)} ll)$	🟨	🟦	🟩	🟩	🟨
B_s Decays					
$B_s \to \mu\mu$	🟥	🟦	🟥	🟩	🟩
β_S from $B_s \to J/\psi\,\phi$	🟥	🟦	🟥	🟩	🟩
$B_s \to \gamma\gamma$	🟥	🟥	🟦	🟥	🟩
a_{sl}	🟥	🟦	🟩	🟩	🟩
D Decays					
Mixing parameters	🟨	🟦	🟩	🟩	🟩
CP Violation	🟥	🟦	🟩	🟩	🟩
Precision Electroweak					
$\sin^2\theta_W$ at $\Upsilon(4S)$	🟥	🟥	🟩	🟥	🟩
$\sin^2\theta_W$ at Z-Pole	🟥	🟦	🟥	🟩	🟨



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α	🟦	🟦	🟩	🟦	🟨
β from $b \to c\overline{c}s$	🟦	🟦	🟩	🟩	🟩
$B_d \to J/\psi\,\pi^0$	🟨	🟥	🟩	🟥	🟩
$B_s \to J/\psi\,K_S^0$	🟥	🟨	🟥	🟦	🟩
γ	🟨	🟦	🟩	🟩	🟩
$\|V_{ub}\|$ inclusive	🟦	🟨	🟩	🟦	🟦
$\|V_{ub}\|$ exclusive	🟦	🟨	🟩	🟦	🟦
$\|V_{cb}\|$ inclusive	🟦	🟨	🟩	🟦	🟦
$\|V_{cb}\|$ exclusive	🟦	🟨	🟩	🟦	🟦

Some relation back to the original programme, but there is a lot more still to explore

????

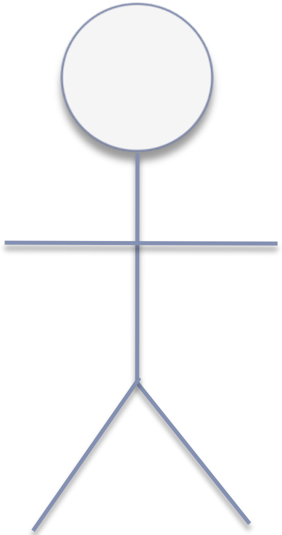
Theoretical uncertainties?

- Input/thought/work is needed on this over the coming months!

- A first basic view:
  - Semi-leptonic decays can be calculated rather cleanly on the Lattice, and the community is starting to actively purse this endeavour.
    - Would be nice to have a review from Vittorio or one of the other experts at a future meeting.

  - Some decays have tiny SD and LD contributions, so are clean to interpret: e.g. D→Xνν.

  - Others have hadronic uncertainties that will require some experimental and theoretical work to improve the understanding.



Summary

Some highlights

- Charm:
  - Time-dependent charm searches for NP
  - Time-integrated CP violation in $D \to \pi^+\pi^0$
  - $D_s \to \ell\nu$
  - $D_s \to X\nu\bar{\nu}$ and $D_s \to X\ell^+\ell^-$
  - $D^0 \to K^0_S h^+h^-$ strong phase difference Dalitz map measurement
  - $D^0 \to KK\pi\pi$ T-odd asymmetries and NP search
  - f_{D_s}
  - $|V_{cd}|$ and $|V_{cs}|$
- τ:
  - $\tau \to \mu\gamma$, $e\gamma$
  - τ EDM
  - CPV in $\tau \to K^0_S\pi\nu$ (and other final states)
  - CPT test (lifetime and mass)
  - $|V_{us}|$
- Precision EW:
  - $\sin^2\theta_W$ for e^+e^-, $\mu^+\mu^-$ and $c\bar{c}$
- Spectroscopy:
  - Collect/Understand X, Y, Z samples - to explore
  - Search for dark photons and dark Higgs particles

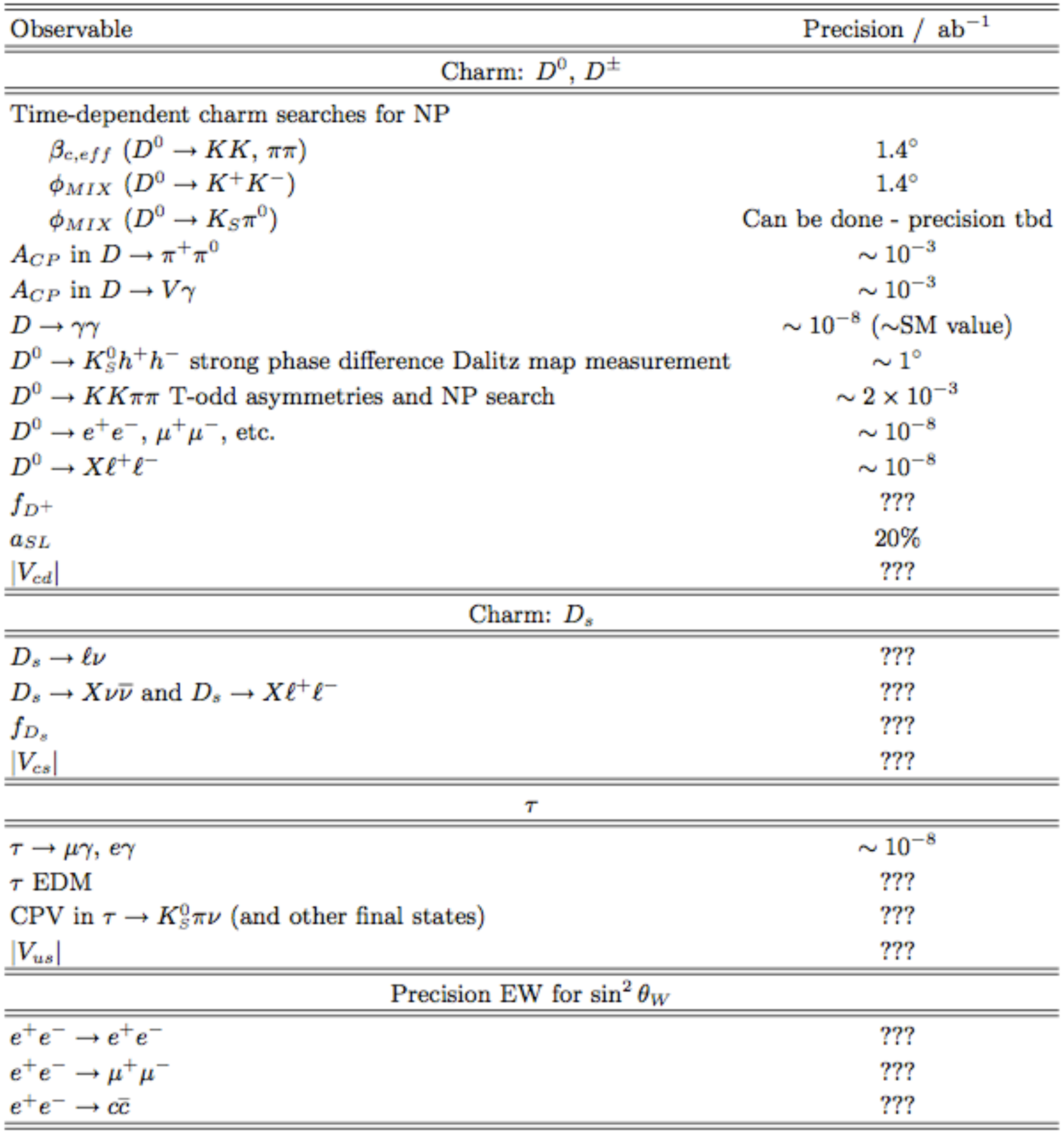
Most (perhaps not all) have been mentioned in this talk.

This is the beginning …

Is it sufficient to form a case for support?

… probably.

and some work to do ...



Observable	Precision / ab^{-1}
Charm: D^0, $D^\pm$	
Time-dependent charm searches for NP	
$\beta_{c,eff}$ $(D^0 \to KK, \pi\pi)$	1.4°
ϕ_{MIX} $(D^0 \to K^+K^-)$	1.4°
ϕ_{MIX} $(D^0 \to K_S\pi^0)$	Can be done - precision tbd
A_{CP} in $D \to \pi^+\pi^0$	$\sim 10^{-3}$
A_{CP} in $D \to V\gamma$	$\sim 10^{-3}$
$D \to \gamma\gamma$	$\sim 10^{-8}$ (∼SM value)
$D^0 \to K^0_S h^+h^-$ strong phase difference Dalitz map measurement	$\sim 1^\circ$
$D^0 \to KK\pi\pi$ T-odd asymmetries and NP search	$\sim 2 \times 10^{-3}$
$D^0 \to e^+e^-$, $\mu^+\mu^-$, etc.	$\sim 10^{-8}$
$D^0 \to X\ell^+\ell^-$	$\sim 10^{-8}$
f_{D^+}	???
a_{SL}	20%
$\lvert V_{cd}\rvert$	???
Charm: D_s	
$D_s \to \ell\nu$	???
$D_s \to X\nu\bar{\nu}$ and $D_s \to X\ell^+\ell^-$	???
f_{D_s}	???
$\lvert V_{cs}\rvert$	???
τ	
$\tau \to \mu\gamma$, $e\gamma$	$\sim 10^{-8}$
τ EDM	???
CPV in $\tau \to K^0_S\pi\nu$ (and other final states)	???
$\lvert V_{us}\rvert$	???
Precision EW for $\sin^2\theta_W$	
$e^+e^- \to e^+e^-$	???
$e^+e^- \to \mu^+\mu^-$	???
$e^+e^- \to c\bar{c}$	???

What about:

Charm Mixing sensitivity (threshold only)?

Majorana neutrino related modes?

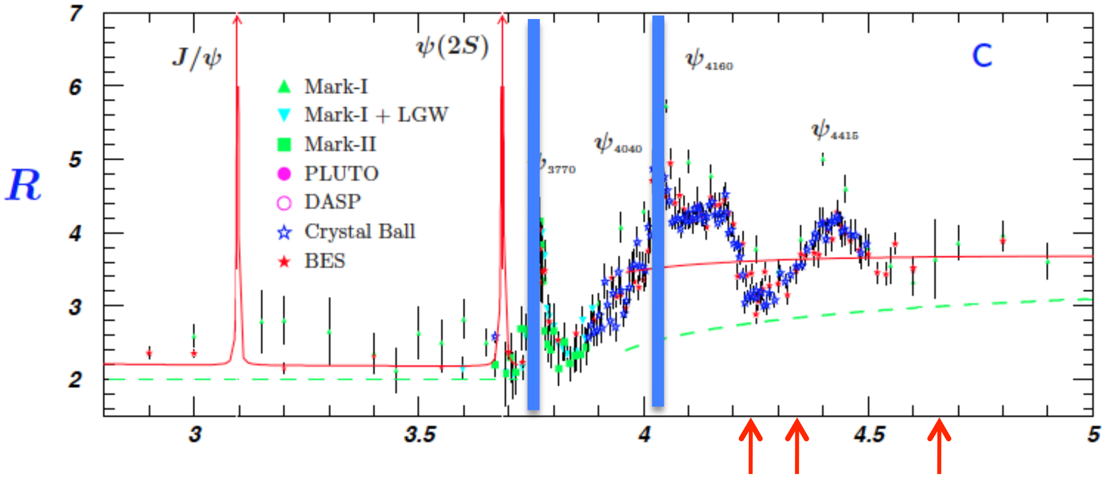
+ Expect that other issues will be raised during this week.

To be investigated

- How do systematic errors scale?
- What about the onset of backgrounds for clean measurements?
- What are the machine backgrounds:
  - Needs to be studied in detail
- What should the detector look like:
  - See Francesco's talk later

What energy(ies) should be run at? (and for how long?)

- Not straightforward to answer: some compromise is required: assume 5 years nominal running.
  - Use physics programme as a guide, starting from the following estimate:
  - ~3ab^{-1} at the ψ(3770)
  - ~4ab^{-1} at other energies (assume 4.03-4.17)
  - Would be useful to also run at: 4260, 4350, 4660 for spectroscopy.
  - Need to discuss feasibility with machine folk



These energies would be optimised for charm (D$_{(S)}$), but good for tau as well.

- *Remember that nothing is set in stone*

What energy(ies) should be run at? (and for how long?)

- Not straightforward to answer: some compromise is required: assume 5 years nominal running.
  - Use physics programme as a guide, starting from the following estimate:
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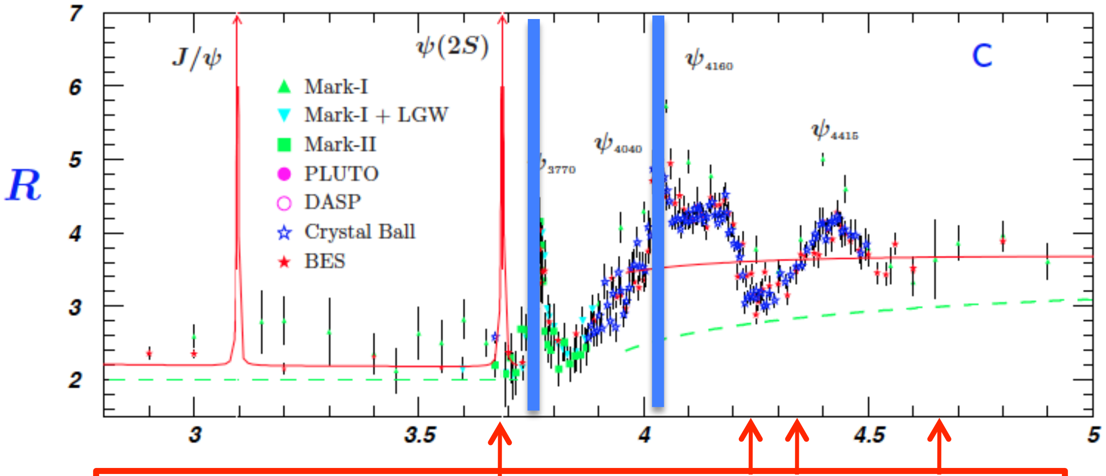


A short run at the ψ(2S) (v. low lumi from the SuperτC perspective) could give a lot more data to analyse than is available at BES III.

This depends on beam energy spread of the machine – don't know what is possible here...

What energy(ies) should be run at? (and for how long?)

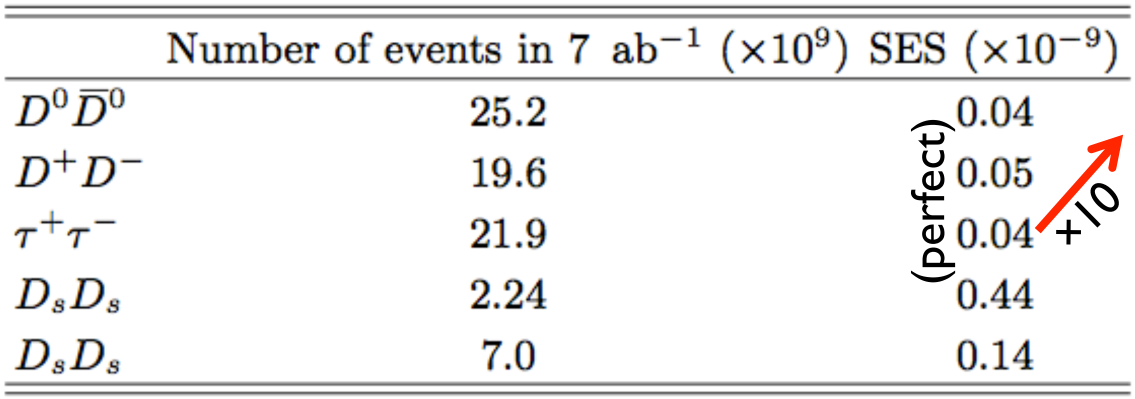
- Not straightforward to answer: some compromise is required: assume 5 years nominal running.
  - Use physics programme as a guide, starting from the following estimate:
  - ~3ab^{-1} at the ψ(3770)
  - ~4ab^{-1} at other energies (assume 4.03-4.17)
  - J/ψ and ψ(2S) listed for completeness

	CM mass	σ (nb)	Number of events/ ab^{-1} ($\times 10^9$)
J/ψ	3.097	3400	3400
$\tau^+\tau^-$	3.670	2.4	2.4
$\psi(2S)$	3.686	640	640
$D^0\overline{D}^0$	3.770	3.6	3.6
D^+D^-	3.770	2.8	2.8
$\tau^+\tau^-$	3.770	2.5	2.5
D_sD_s	4.030	0.32	0.32
D_sD_s	4.170	1.0	1.0
$\tau^+\tau^-$	4.25	3.6	3.6

- *Remember that nothing is set in stone*

Estimated yields

- Aim for 7ab^{-1} at near/charm threshold (c.f. 500-1000fb^{-1})
- SES quoted for perfect reconstruction, no background: i.e this is as good as it ever gets:
  - Reality is probably an order of magnitude off of the SES numbers quoted below



	Number of events in 7 ab^{-1} ($\times 10^9$)	SES ($\times 10^{-9}$)
$D^0\overline{D}^0$	25.2	0.04
D^+D^-	19.6	0.05
$\tau^+\tau^-$	21.9	0.04
D_sD_s	2.24	0.44
D_sD_s	7.0	0.14

Expect an SES of ~0.4-4e-9 for rare decay searches.

Needs to be investigated on a mode-by-mode basis.

- These samples are massive compared to anything else collected at threshold. τ$^+$τ$^-$ sample ~1/3 of a 4S machine like SuperB.

A personal interpretation

- I think that there is a lot of good physics that can be done by a SuperτC.
- A first pass at compiling a list of main measurements can be done from this talk... but this is only a start
- It obviously will need to be refined in the context of the machine and the detector.
  - That discussion needs to be started: See Francesco's talk after coffee.
- Can form the basis of an experimental programme if there is a community interested in the physics *AND* if the timescale of any new project is appropriate.

Next steps … ?

- Initial formulation of the physics programme
  - Compile a list of theoretically clean (or controllable) observables that can test NP and the SM.
  - List the state of the art in terms of theory/Lattice to support the above list where available.
  - Highlight models of NP that can manifest large effects.

Should happen now

- Longer term view
  - The Lattice roadmap a la SuperB should be revisited.
    - The job should be easier for a SuperτC, but one should check that everything required is covered.
  - Other theory errors should be interrogated.
  - Simulation to refine understanding of the initial programme view.

Something to start in 2013

Some Background Reading

The following slide is intended to be used as a starting point for anyone whishing to better understand the potential programme

- Our documents
  - CDR (arXiv:0709.0451)
  - SuperB White Paper (arXiv:1008.1541)
  - SuperB Physics note: SB-PHY-2012-20
- BES III Physics Book (arXiv:0809.1869)
- KLOE 2 Physics Book (arXiv:1003.3868)
- Novosibirsk SuperτC
  - (http://www1.jinr.ru/Pepan_letters/panl_7_2008/02_lev.pdf)
- Stahl's book on tau decays
- Physics of the B Factories chapters on charm and tau
  - This is not yet publicly available: but BaBar/Belle collaborators have access to this text: expect it to be public March/April 2013.
- + references cited throughout

Please note that this is a partial list of potential references, due to time constraints it has not been possible to develop a more comprehensive bibliography.

Additional material

A collection of "back up slides" that may be useful as a reference for people interested in exploring further.

Introduction

- What is rare?
  - CLEO-c at ψ(3770): 0.8fb^{-1} (~3.2×10^{6} D pairs)
  - BES III at ψ(3770): ~10fb^{-1} (~40×10^{6} D pairs)
  - SuperB at ψ(3770): 500fb^{-1} (~2×10^{9} D pairs)
    - Two large jumps in data samples could change the perspective on rare decays with time ...
    - Superb will approach a single event sensitivity at ~10^{-9}

  - BaBar/Belle at the ϒ(4S): ~0.5-1ab^{-1} of data [0.6-1.2 $\times10^{9}$ events]
  - SuperB/Belle II at the ϒ(4S): 50-75ab^{-1} of data [60-90 $\times10^{9}$ events]
    - Rely on D* tagged mesons, not always the best (but with 50 times more data than at threshold)

  - LHCb:
    - Vast numbers in a hadronic environment: good for charged track final states if channel can be triggered on efficiently.
    - Not so good with neutral final states (ν's, γ's, π^0's etc.)

From Bevan @ Charm WS 2011

Neutral final states

$$D \to \pi^0\pi^0$$

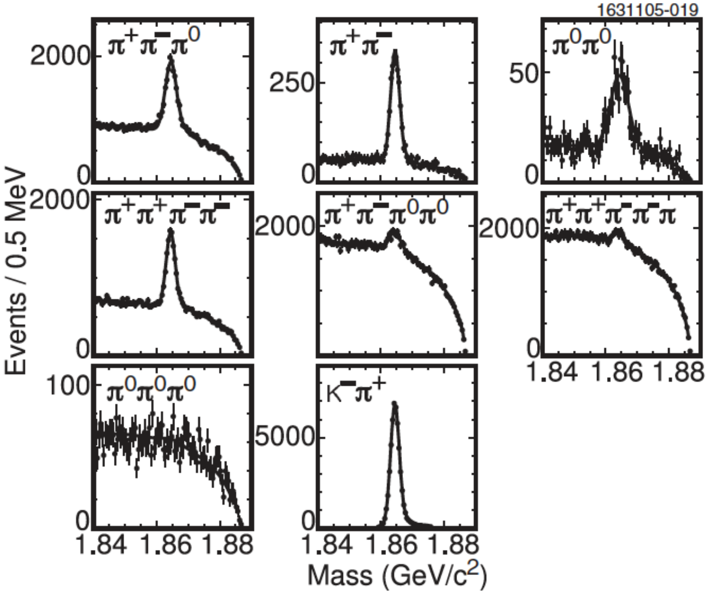
$$D \to \gamma\gamma$$

From Bevan @ Charm WS 2011

$D \to \pi^0\pi^0$

- Not particularly rare... but
  - Input to the Isospin analysis required to constrain penguin pollution for the TDCPV measurement of $\pi^+\pi^-$ (see Brian Meadows' talk).
  - Also background to other rare decays (would be nice to determine this a bit more precisely).

$$\mathcal{B}(D^0 \to \pi^0\pi^0) \quad = \quad (8.0 \pm 0.8) \times 10^{-4} \qquad \text{(CLEO)}$$

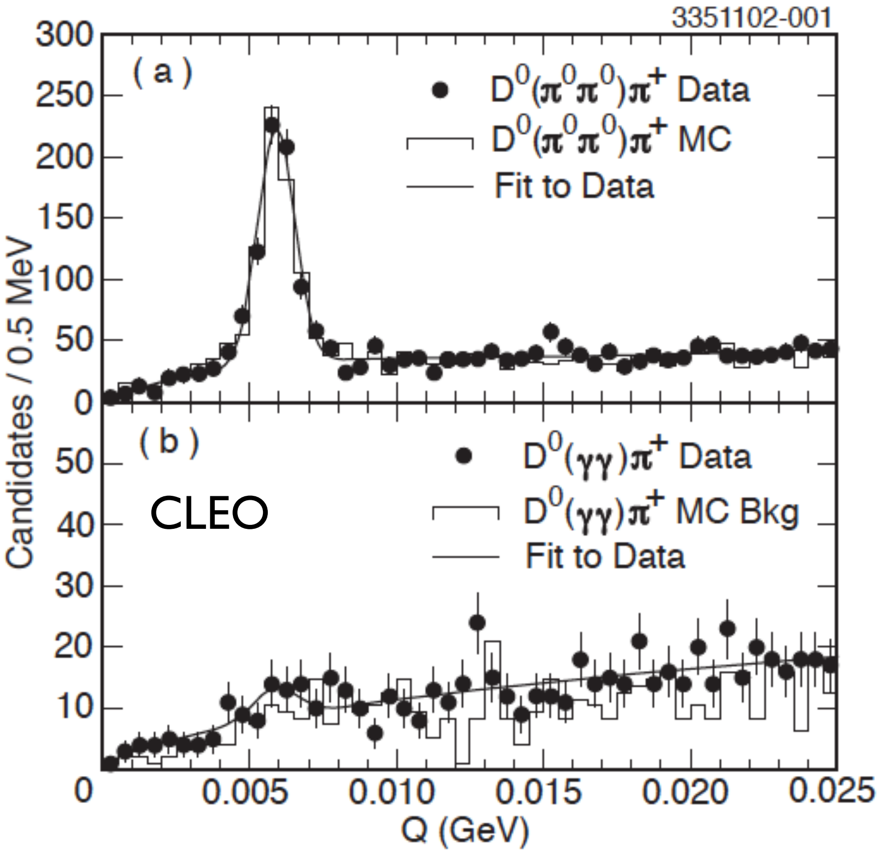


- CLEO recorded 500 events in a sample of 0.281fb^{-1}.
- ε ~30%.
- but dominated by systematic uncertainties (comparable syst. & stat. errors).
- Some improvement possible, but will be dominated by the ultimate systematic errors achievable.

From Bevan @ Charm WS 2011

$D \to \gamma\gamma$

- CLEO data PRL **90** 201801 (2003) using 13.8 fb^{-1} of data.



- Measured $\gamma\gamma/\pi^0\pi^0$

- Current value reported in PDG $<2.7\times10^{-5}$.

- Measurement used D* tagged events from the 4S data sample to isolate signal region.

- Systematic uncertainties dominated by π and γ reconstruction efficiencies.

From Bevan @ Charm WS 2011

Rare Leptonic decays

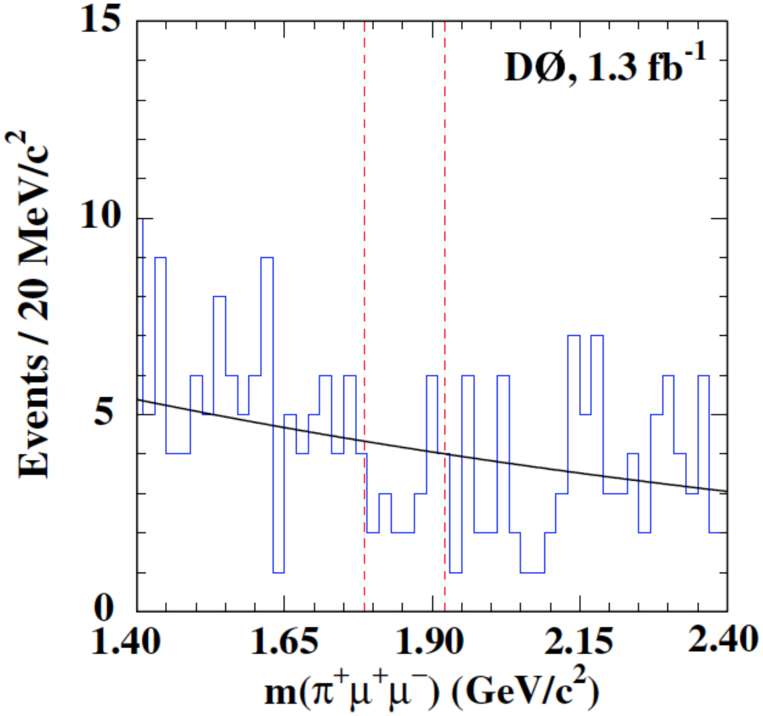
$$D \to \ell^+ \ell^-$$

$$D \to u \ell^+ \ell^-$$

From Bevan @ Charm WS 2011

$D \to u\ell^+\ell^-$: The D0 result

- D0 searched for $c \to u\mu^+\mu^-$ transitions: PRL **100** 101801 (2008)
  - Vetoing the resonance however shows no evidence for signal...



D0 place an upper limit on this channel of (excluding the ϕ):

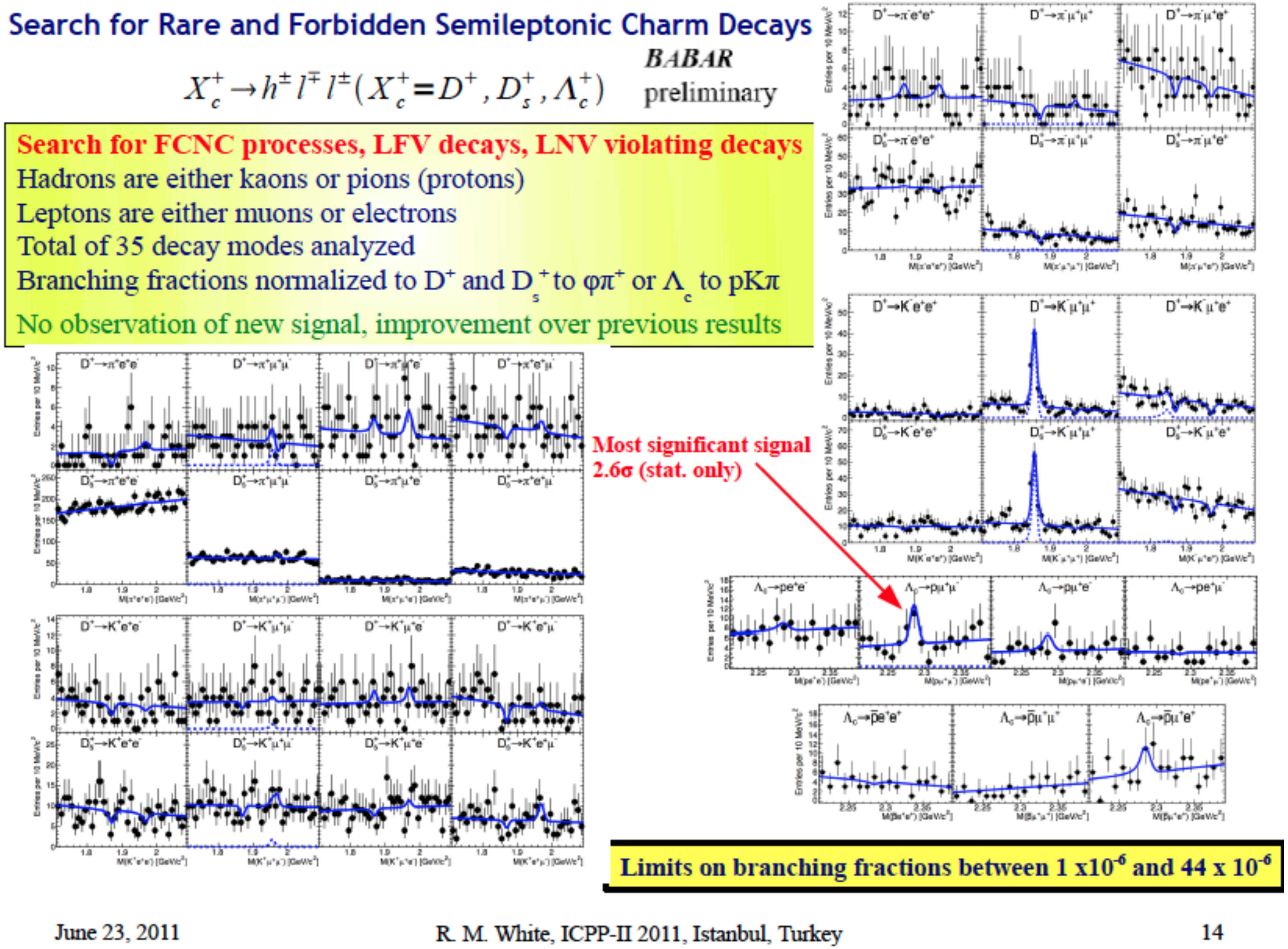
$$< 3.9 \times 10^{-6} \ (90\%, C.L.)$$

Given that enhancement depends on q^2 of the di-lepton pair, we want to analyse both ee and μμ channels.

SuperB should be able to probe sensitivities down to ~1×10^{-8}.

From Bevan @ Charm WS 2011

Search results from BaBar



Search for Rare and Forbidden Semileptonic Charm Decays

$X_c^+ \to h^\pm l^\mp l^\pm (X_c^+ = D^+, D_s^+, \Lambda_c^+)$

BABAR preliminary

Search for FCNC processes, LFV decays, LNV violating decays

Hadrons are either kaons or pions (protons)

Leptons are either muons or electrons

Total of 35 decay modes analyzed

Branching fractions normalized to D^+ and D_s^+ to $\varphi\pi^+$ or Λ_c to $pK\pi$

No observation of new signal, improvement over previous results

Most significant signal 2.6σ (stat. only)

Limits on branching fractions between 1 x10^{-6} and 44 x 10^{-6}

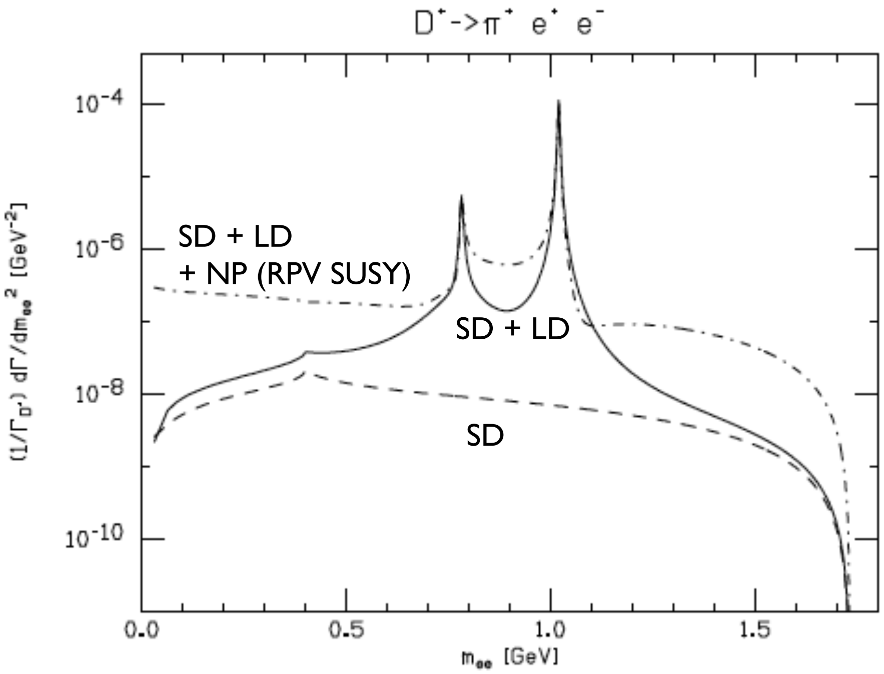
June 23, 2011 R. M. White, ICPP-II 2011, Istanbul, Turkey 14

From Bevan @ Charm WS 2011

$D \to u\ell^+\ell^-$

- Exclusive BRs:

Channel	Sensitivity	BR (th.)	UL (expt.)
$D^0 \to \pi^0\ell^+\ell^-$	2×10^{-8}	0.8×10^{-6}	4.5×10^{-5} (CLEO)
$D^+ \to \pi^+\ell^+\ell^-$	1×10^{-8}	2×10^{-6}	$< 3.9\times10^{-6}$ (D0)
$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}	–	
$D^+ \to h^-\ell^+\ell^+$ $(h=\pi,K)$	1×10^{-8}	–	$< 3.6\times10^{-6}$ (CLEO)
$D^+ \to h^- e^\pm\mu^\mp$ $(h=\pi,K)$	1×10^{-8}	–	$< 3.4\times10^{-6}$ (CLEO)



Differential rate is dominated by contributions from Φ and ω resonances.

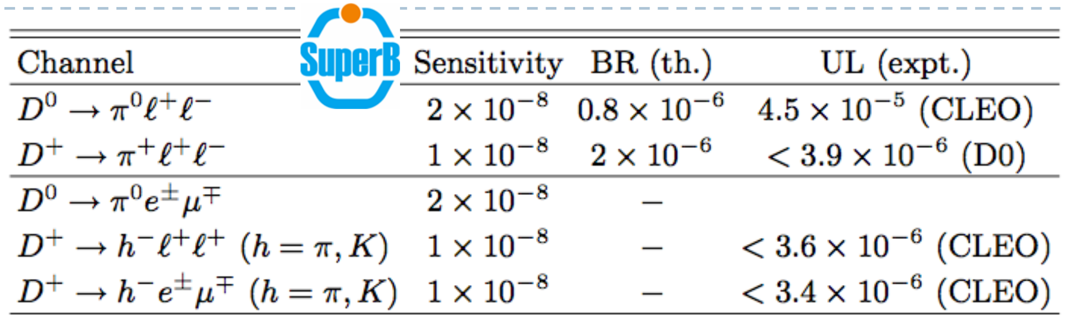
LD saturates SD effects, but NP enhancements can be clearly determined (away from resonant structure).

Burdman & Shipsey hep-ph/0310076

From Bevan @ Charm WS 2011

$D \to u\ell^+\ell^-$

- Exclusive BRs:



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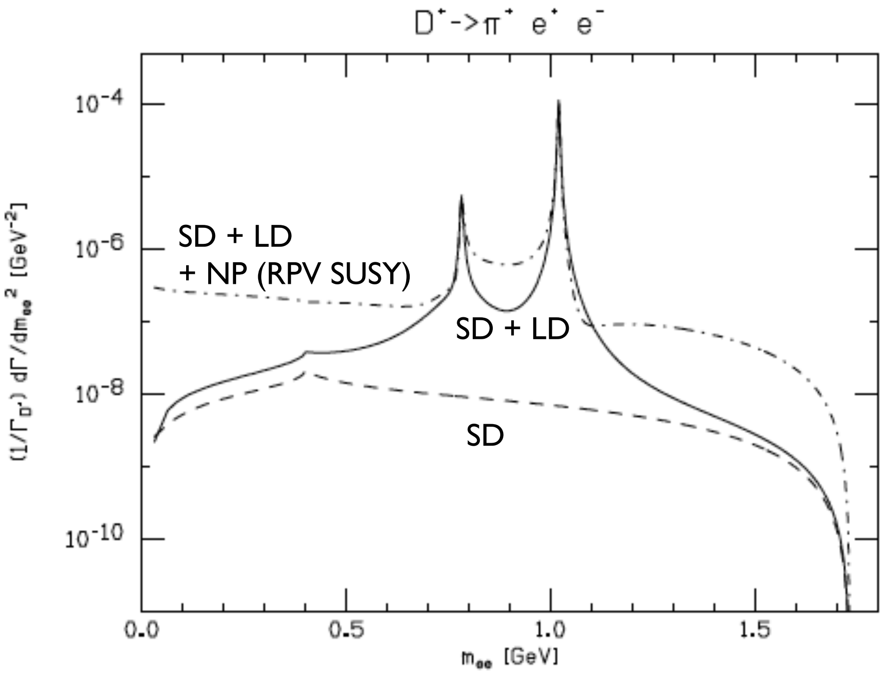

Broadly speaking there are 3 regions of interest:

- Low q^2 (below resonances)
- High q^2 (above resonances)
- in between resonances (challenging?)

Easier to see NP effects away from resonant structure.

SuperB can start probing this.

Burdman & Shipsey hep-ph/0310076

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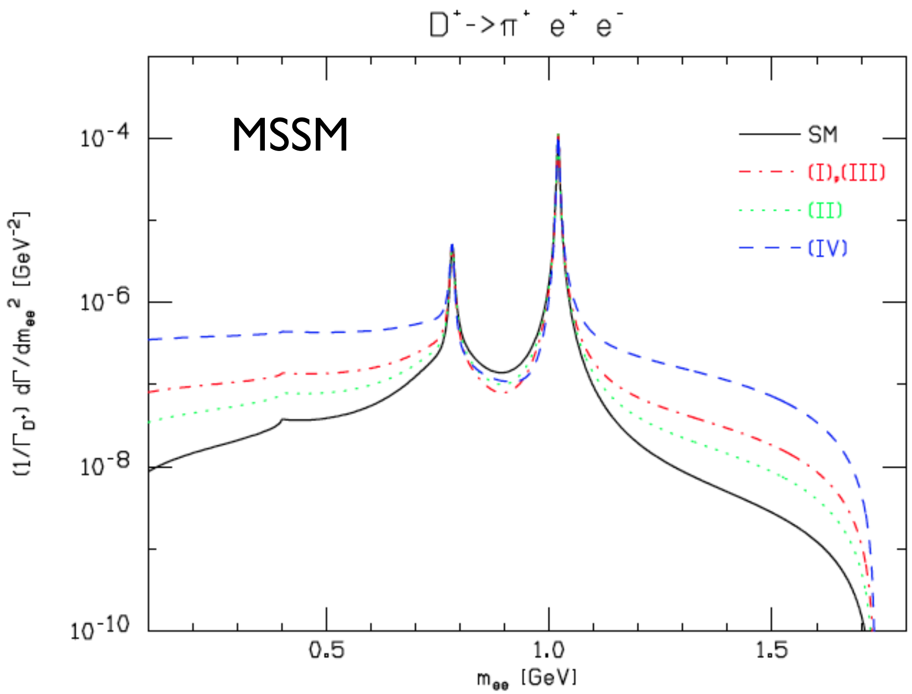

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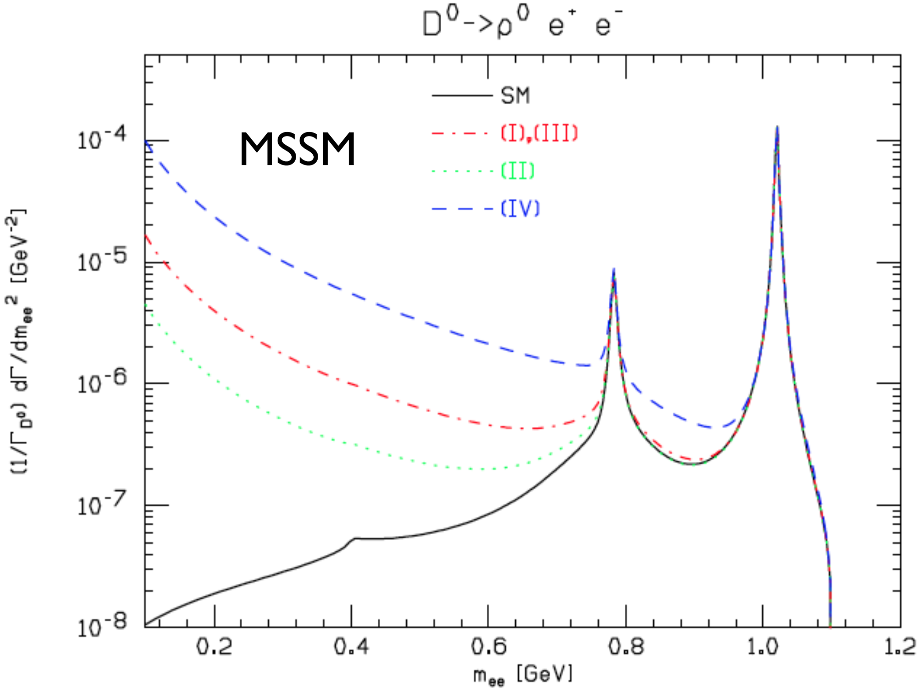


N.B. ρℓℓ has a larger enhancement at low di-lepton mass.

Experimentally more challenging, but could provide a clearer signal for NP.

Low q^2 region is of most interest, so e^+e^- is potentially much more interesting than $\mu^+\mu^-$.

Burdman & Shipsey hep-ph/0310076

Final states with missing energy

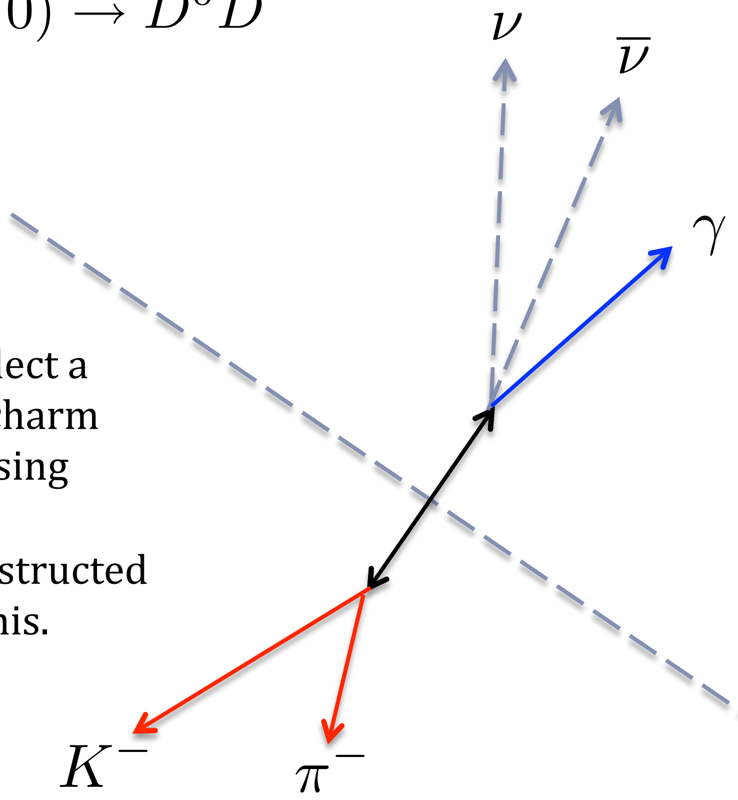
$$D \rightarrow \nu\overline{\nu}(+\gamma)$$

$$D \rightarrow X_u\nu\overline{\nu}$$

From Bevan @ Charm WS 2011

D recoil method

- Here we need to resort to D recoil methodology to reconstruct the event.
  - e.g. $\psi(3770) \to D^0\overline{D}^0$



• Use tag D to select a pure sample of charm decays with missing energy.
• Use fully reconstructed final states for this.

• Missing energy used to discriminate signal from background.
• Any other particles in the event can be used to add discrimination.

Cartoon of the CM frame

From Bevan @ Charm WS 2011

$D \to \nu\overline{\nu}(+\gamma)$

- Helicity suppressed in the Standard Model
  - BF ~ 1.1×10^{-30}
  - The final state with a photon is much more copious: 10^{-14}
  - Beyond the SM one could find significant enhancements
    - e.g. scalar particles such as DM candidates: PRD **82**:034005, 2010.
  - Require either an isolated photon in the detector ($\nu\overline{\nu}\gamma$), or nothing ....
    - Experimentally challenging: backgrounds include where both particles go down the beam pipe... e.g. $D \to K\pi$
    - $\nu\overline{\nu}\gamma$ has the added advantage of the photon (and smaller allowed phase space for NP).
    - Also worth searching for the corresponding D_s decays ... see next topic.

+ Analogues for $B_{d,s}$ and K decays

From Bevan @ Charm WS 2011

$D \to X_u \nu\overline{\nu}$

- Similar to the invisible decay searches...
  - Can perform inclusive or exclusive measurements, both sets of measurements will provide more information to constrain NP.
    - Analogy with $B \to X\nu\overline{\nu}$
    - Similar interest for $D_s \to X_s\nu\overline{\nu}$
  - LD contributions should be small, and SM rate is tiny

$$\begin{aligned} \mathcal{B}(B^+ \to X_u\nu\overline{\nu}) &\simeq 1.2 \times 10^{-15} \\ \mathcal{B}(B^0 \to X_u\nu\overline{\nu}) &\simeq 5 \times 10^{-16} \end{aligned}$$

Bigi & Paul arXiv:1110.2862

From Bevan @ Charm WS 2011

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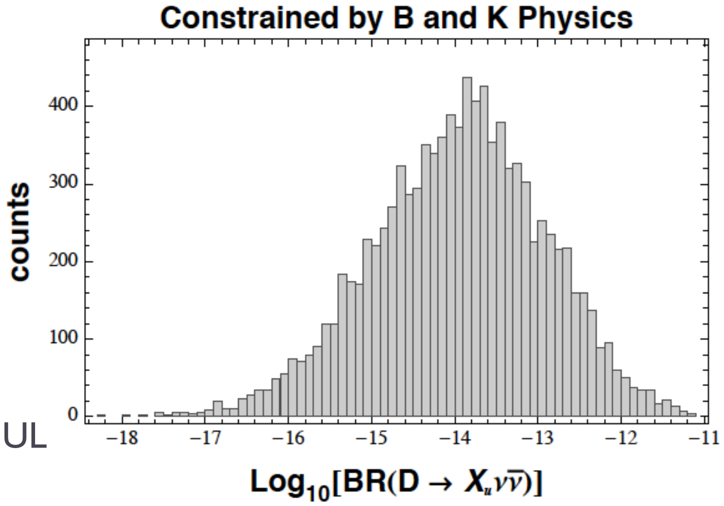
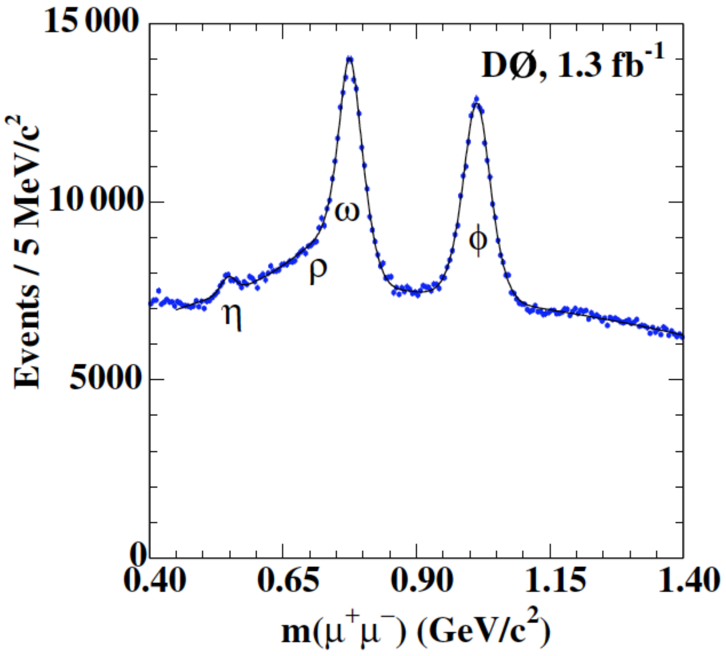
- Large enhancements possible in NP models
  - Up to ×1000 in LHT models
- Plausibly could reach ~10^{-8} with SuperB at threshold, need to study potential for D* tagged samples.
- π^0 mode is worth searching for as an indication for CPV.

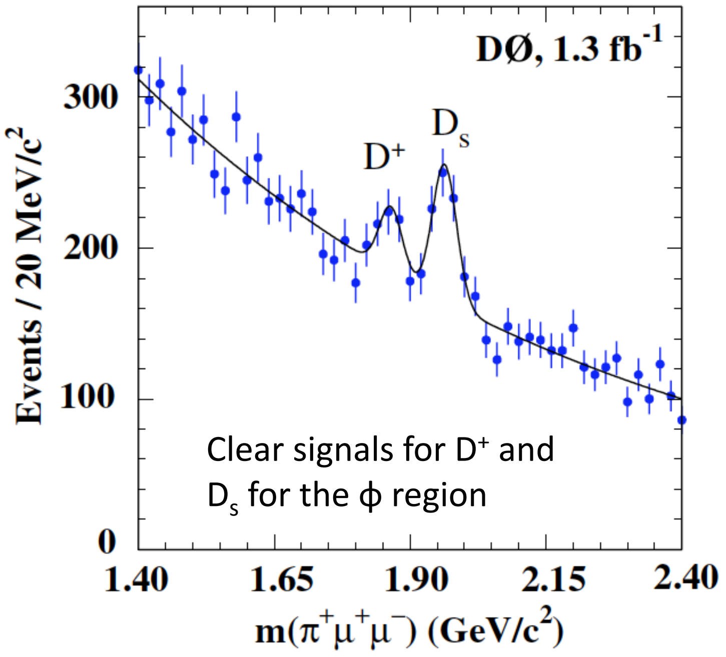


Bigi & Paul arXiv:1110.2862

$D \to u\ell^+\ell^-$: The D0 result

- D0 searched for $c \to u\mu^+\mu^-$ transitions: PRL **100** 101801 (2008)
  - Clearly visible signal around resonances, however there is a lot of background...





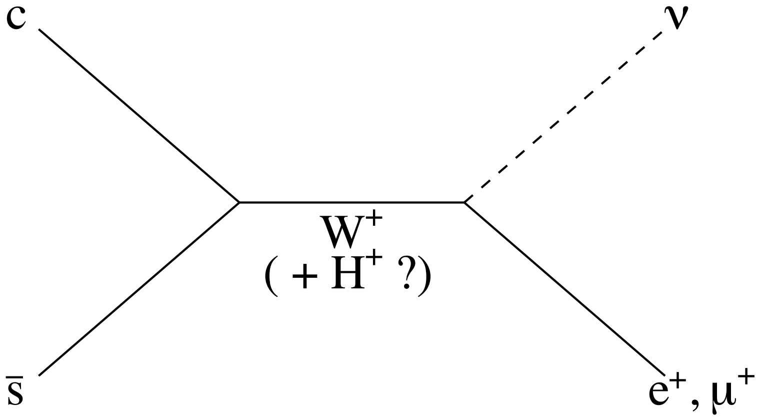
Clear signals for D$^+$ and D$_s$ for the ϕ region

CLEO, FOCUS and BaBar have results on FCNC searches as well

From Bevan @ Charm WS 2011

$D^+_{(s)} \to \ell^+\nu_\ell$

- Complementary to $B^+ \to \ell^+\nu_\ell$



$$\Gamma(D^+ \to \ell^+\nu) = \frac{G_F^2}{8\pi} f_{D^+}^2 m_\ell^2 M_{D^+}\left(1 - \frac{m_\ell^2}{M_{D^+}^2}\right)^2 |V_{cd}|^2$$

$$\Gamma(D_s^+ \to \ell^+\nu) = \frac{G_F^2}{8\pi} f_{D_s^+}^2 m_\ell^2 M_{D_s^+}\left(1 - \frac{m_\ell^2}{M_{D_s^+}^2}\right)^2 |V_{cs}|^2$$

- Can also test lepton universality with ratios of rates.

- Lots of excitement a few years ago because of a discrepancy with f_{Ds} from lattice ... unfortunately this was not a sign of NP.
- CLEO find:

$$\begin{aligned}
\mathcal{B}(D_s^+ \to e^+\nu) &= < 1.2 \times 10^{-4}(90\%\, C.L.) \\
\mathcal{B}(D_s^+ \to \mu^+\nu) &= (0.565 \pm 0.045 \pm 0.017)\% \\
\mathcal{B}(D_s^+ \to \tau^+\nu) &= (6.42 \pm 0.81 \pm 0.18)\%
\end{aligned}$$

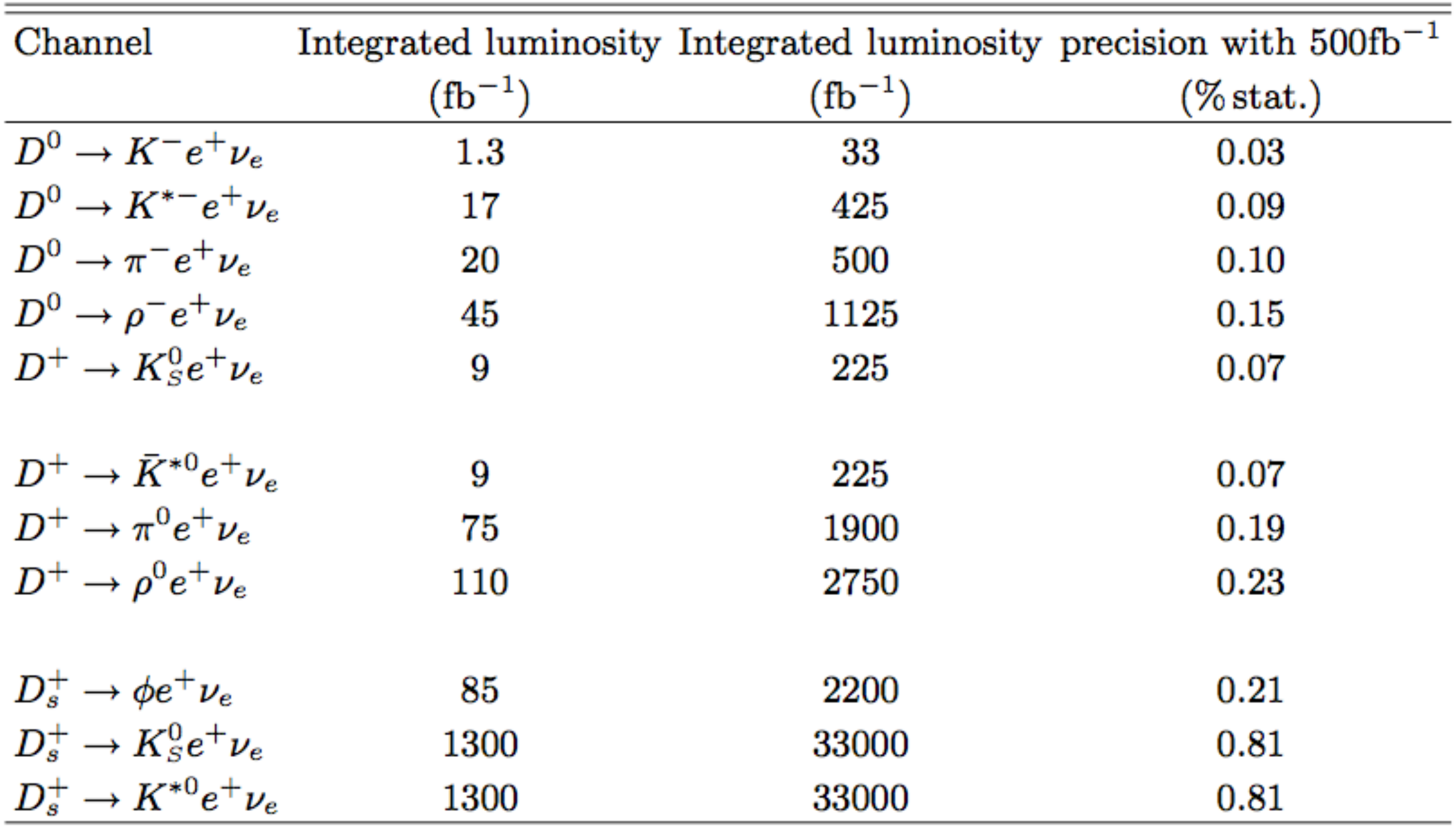
- which are compatible with SM expectations.

Phys. Rev. D**79** 052001 (2009)

From Bevan @ Charm WS 2011

Summary

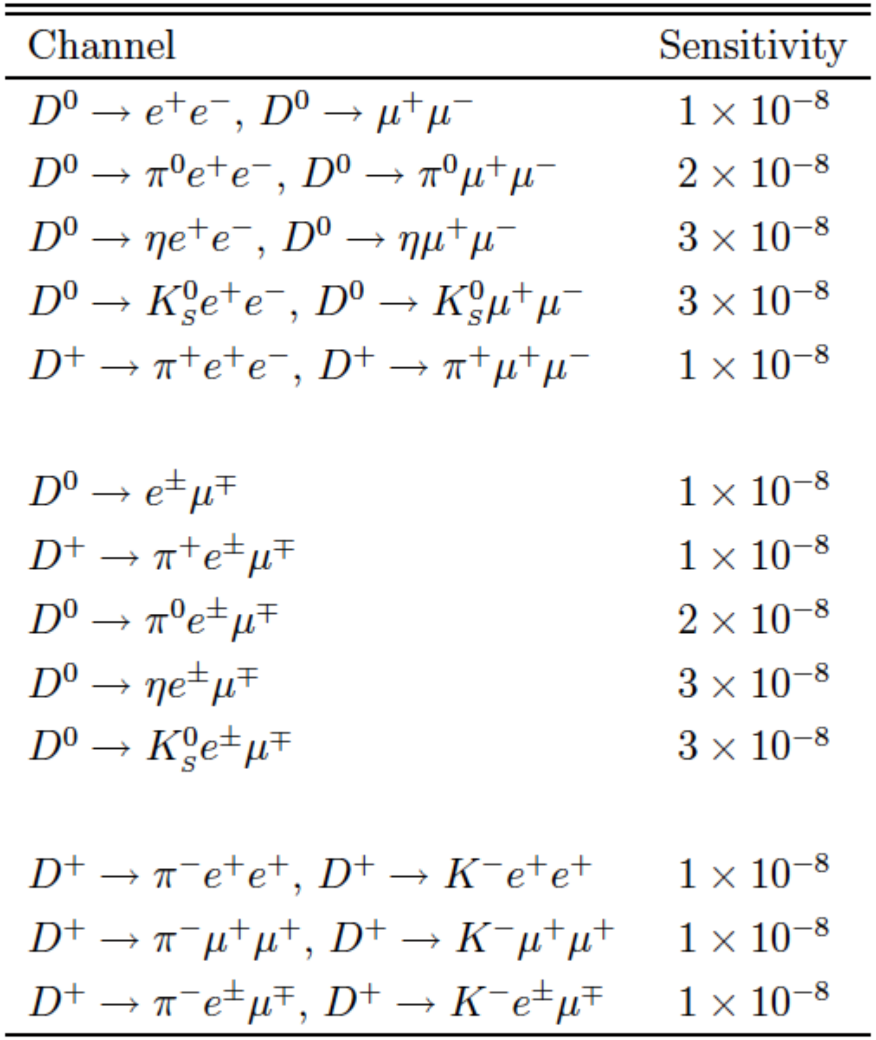
- Indication of luminosities required to reach 0.5% statistical precision on different modes vs. precision at 500fb^{-1}:



Channel	Integrated luminosity (fb^{-1})	Integrated luminosity (fb^{-1})	precision with 500fb^{-1} (% stat.)
$D^0 \to K^- e^+ \nu_e$	1.3	33	0.03
$D^0 \to K^{*-} e^+ \nu_e$	17	425	0.09
$D^0 \to \pi^- e^+ \nu_e$	20	500	0.10
$D^0 \to \rho^- e^+ \nu_e$	45	1125	0.15
$D^+ \to K_S^0 e^+ \nu_e$	9	225	0.07
$D^+ \to \bar{K}^{*0} e^+ \nu_e$	9	225	0.07
$D^+ \to \pi^0 e^+ \nu_e$	75	1900	0.19
$D^+ \to \rho^0 e^+ \nu_e$	110	2750	0.23
$D_s^+ \to \phi e^+ \nu_e$	85	2200	0.21
$D_s^+ \to K_S^0 e^+ \nu_e$	1300	33000	0.81
$D_s^+ \to K^{*0} e^+ \nu_e$	1300	33000	0.81

From Bevan @ Charm WS 2011

Summary



Channel	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_S e^+e^-$, $D^0 \to K^0_S\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_S e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^-e^+e^+$, $D^+ \to K^-e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^-e^\pm\mu^\mp$, $D^+ \to K^-e^\pm\mu^\mp$	1×10^{-8}

- Great potential to search for NP and understand the rare branching fractions in charm.
- Threshold running will give SuperB another angle, and make it competitive compared to the previous generation.
  - Was not always the case with 4S for BaBar and Belle.

From Bevan @ Charm WS 2011

Summary

- A number of interesting rare decays to study
  - In many cases can complements searches that can be performed at φ and ϒ(4S) resonances.
  - Provides a clean environment to study low multiplicity states:
    - Help understand the detector hermiticity for more complicated environments such as ϒ(4S) and ϒ(5S).
  - Correlations between decays need to be understood
    - i.e. what can we learn about NP from this set of modes.
    - & where do long distance contributions wash out NP effects?
  - Many interesting decays have been ignored, and quite a few discussed here need to be studied in detail on SuperB
    - If people want to work on this area, extra effort would be welcome.
    - .... lets start the discussion.

From Bevan @ Charm WS 2011

Prospects for Observing CPV in Mixing

- Best strategy may be to improve precision in x_D & y_D - say to ~1×10^{-4}
  - D^0-$\overline{D}^0$ asymmetries ~ $|q/p|^2-1$

Dependence on decay mode would indicate direct CPV?

- Several possibilities for this exist. Most likely are:
  - LHCb (or CDF, Atlas, CMS ?)
  - Super B factories

LHC is performing extremely well !

Machines are on the way !

- A rather safe estimate for performance can be made by using Babar as basis to project to integrated luminosity of 75 ab^{-1} at $\Upsilon(4S)$ anticipated for SuperB *(Similarly for Belle and Super KEKB)*

- We can also speculate on what "SuperD[1]" [500 fb^{-1} at $\psi(3770)$] might accomplish

  [1] See SuperB white paper: *http://arxiv.org/abs/1008.1541)*

From Meadows @ Charm WS 2011

CPV Parameters $|q_D/p_D|$, ϕ_M=Arg{q/p}

- Several strategies:

Current World Averages (HFAG):

	Decay mode	$\sigma(\lvert q/p \rvert)$ x 100	$\sigma(\phi_M)^0$
Global χ^2 Fit to all modes: (HFAG - direct CPV allowed)		±18	± 9

D^0- $\overline{D}^0$ parameter asymmetries:

$a_z = (z_+ - z_-)/(z_+ + z_-) \sim |q|^2 - |p|^2$

where z is x, y, x', y', x", y", x'^{2}

Asymmetries a_z:			
x	<All modes>	±1.8	–
y	<All modes>	±1.1	–
y_{CP}	K^+K^-	±3.8	–
y'	$K^+\pi^-$	±4.9	–
x'^2	$K^+\pi^-$	±4.9	–
x''	$K^+\pi^-\pi^0$	±5.4	–
y''	$K^+\pi^-\pi^0$	±5.0	–

Time-dependent amplitude analysis of Golden channels

Model for $\mathcal{A}_f$	$K_sh^+h^-$	±8.4	±3.3
BES III DP model	$K_sh^+h^-$	±3.7	±1.9
SuperB DP model	$K_sh^+h^-$	±2.7	±1.4

Semi-leptonic asymmetry

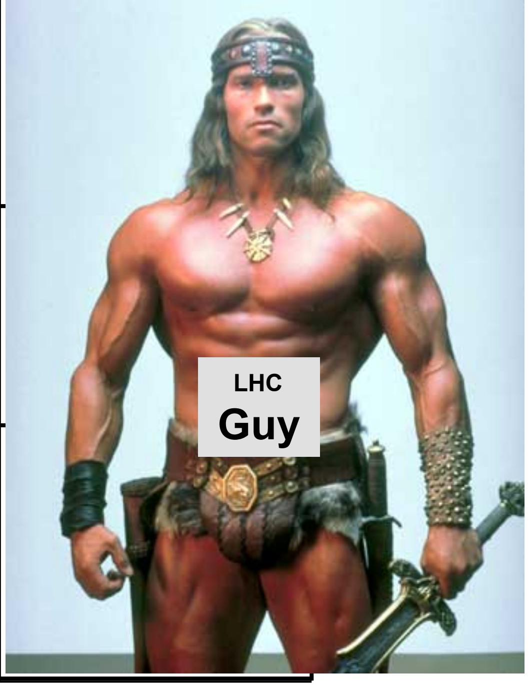
$$a_{SL} = \frac{1-|q/p|^4}{1-|q/p|^4}$$

75 ab^{-1} at $\Upsilon(4S)$	$X\ell\nu_\ell$	±10	
500 fb^{-1} at $\psi(3770)$	$K\pi$-$K\pi$	±10	
500 fb^{-1} at $\psi(3770)$	$X\ell\nu_\ell$	??	

Improve present precision by order of magnitude
Also improve distinction between decay modes ~ 5%

From Meadows @ Charm WS 2011

What About LHCb (10 fb^{-1}) ?

Decay Mode	*BABAR* (480 fb^{-1})	SuperB/Belle (75 ab^{-1})	LHCB (10 fb^{-1})
K^+K^- (D^*-tag):			
N (Events)	88×10^3	13.7×10^6	
Δy_{CP} (stat)	$\pm 3.5 \times 10^{-3}$	0.28×10^{-3}	
K^+K^- (no tag):			
N (Events)	330×10^3	51.4×10^6	
Δy_{CP} (stat)	$\pm 2.3 \times 10^{-3}$	0.19×10^{-3}	
$K^+\pi^-$ (WS):			
N (Events)	5.1×10^3	0.79×10^6	
$\Delta y'$ (stat)	$\pm 4.4 \times 10^{-3}$	0.31×10^{-3}	
$\Delta x'^2$ (stat)	$\pm 3.0 \times 10^{-4}$	0.21×10^{-4}	

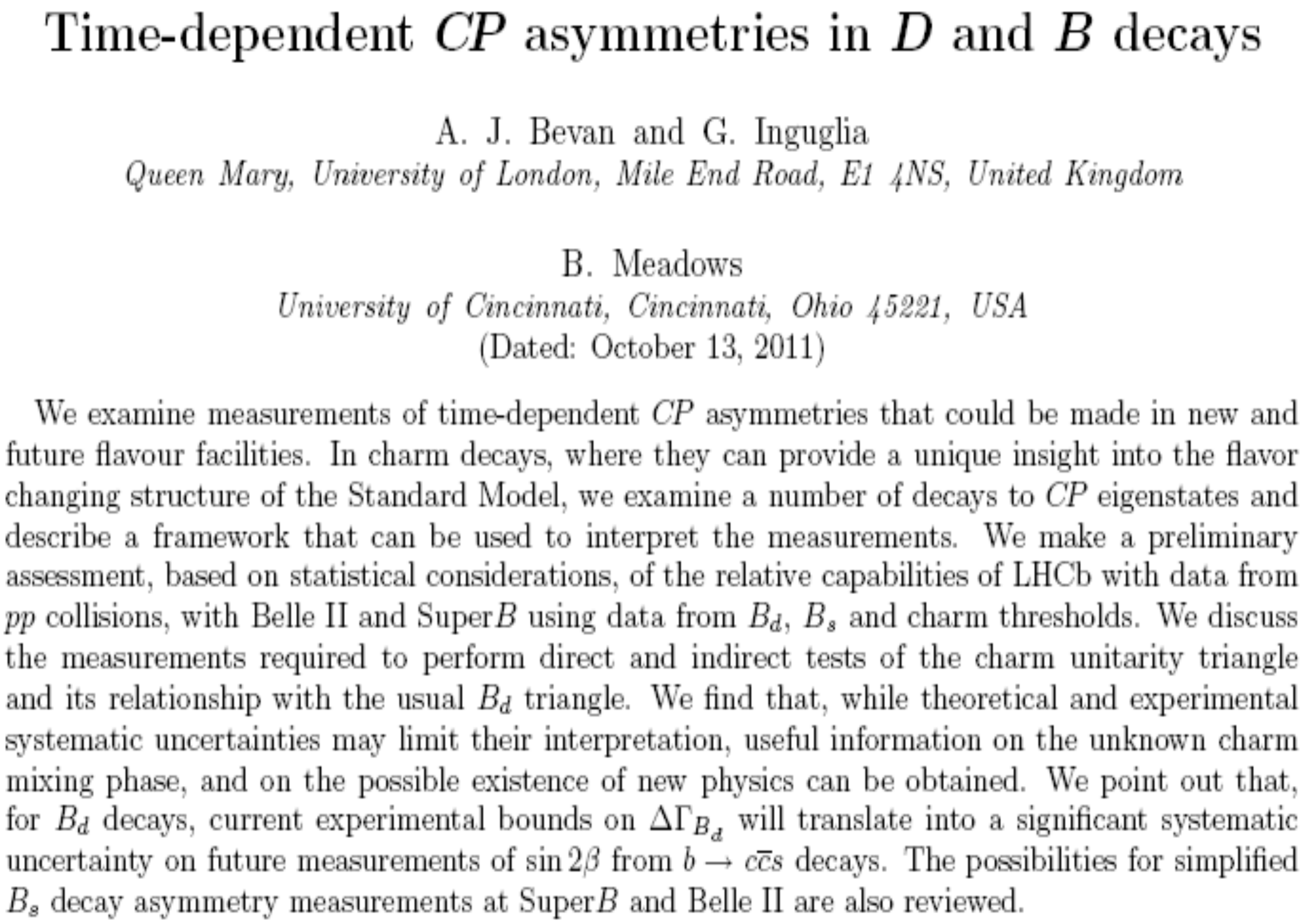
LHCb is running now - doing better than was anticipated

G. Wilkinson P. M. Spradlin CERN-lhcb-2007-049.
P. M. Spradlin (2007), Arxiv: 0711.1661.

At 69 pb^{-1} it is at ~10xBaBar
In channels like $D^0 \rightarrow h^+h^-$

- Considerably less in multi-body channels

From Meadows @ Charm WS 2011



Time-dependent CP asymmetries in D and B decays

A. J. Bevan and G. Inguglia
Queen Mary, University of London, Mile End Road, E1 4NS, United Kingdom

B. Meadows
University of Cincinnati, Cincinnati, Ohio 45221, USA

(Dated: October 13, 2011)

We examine measurements of time-dependent CP asymmetries that could be made in new and future flavour facilities. In charm decays, where they can provide a unique insight into the flavor changing structure of the Standard Model, we examine a number of decays to CP eigenstates and describe a framework that can be used to interpret the measurements. We make a preliminary assessment, based on statistical considerations, of the relative capabilities of LHCb with data from pp collisions, with Belle II and Super$B$ using data from B_d, B_s and charm thresholds. We discuss the measurements required to perform direct and indirect tests of the charm unitarity triangle and its relationship with the usual B_d triangle. We find that, while theoretical and experimental systematic uncertainties may limit their interpretation, useful information on the unknown charm mixing phase, and on the possible existence of new physics can be obtained. We point out that, for B_d decays, current experimental bounds on $\Delta\Gamma_{B_d}$ will translate into a significant systematic uncertainty on future measurements of $\sin 2\beta$ from $b \to c\bar{c}s$ decays. The possibilities for simplified B_s decay asymmetry measurements at Super$B$ and Belle II are also reviewed.

ArXiv: 1106.5075v2

From Meadows @ Charm WS 2011

Why is this Interesting for *D*'s Too ?

- Bigi and Sanda (hep-ph/9909479v2) pointed out there are six unitarity triangles and that (in addition to α, β and γ) two other angles, β_c and β_s should be measured if possible.
  - LHCb is already working on β_s using $B_s \to \psi\phi(f_0)$ decays.
  - SuperB and Belle2 should also be able to study $B_s \rightarrow \psi\eta^{(')}$ at Υ(5S)
- We explore, for first time, potential to study the *"cu"* triangle.
  - It is unlikely we can measure β_c(<0.1 degrees) to high precision
  - However, a larger value would signify new physics.
- A TDCPV analysis can also measure ϕ_M, the mixing phase, whose HFAG average value is $\phi_M = (-10 \pm 12)^0$.
- The mixing angle is intrinsically of great interest.

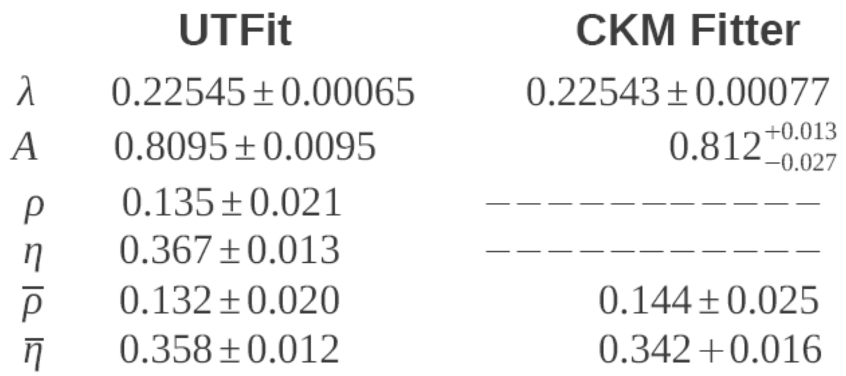
From Meadows @ Charm WS 2011

CKM Predictions

- A number of CKM predictions are compared to observables

  ε_K, ΔM_d, ΔM_s, BF($B \to \tau\nu$), alpha, sin2β, γ, V_{cb}, lattice, ...

  Fits to measured values give values for CKM parameters:



	UTFit	CKM Fitter
λ	0.22545 ± 0.00065	0.22543 ± 0.00077
A	0.8095 ± 0.0095	$0.812^{+0.013}_{-0.027}$
ρ	0.135 ± 0.021	————————————
η	0.367 ± 0.013	————————————
$\bar{\rho}$	0.132 ± 0.020	0.144 ± 0.025
$\bar{\eta}$	0.358 ± 0.012	$0.342 + 0.016$

Significant discrepancies may exist:

sin2β ~3σ low
BF($B \to \tau\nu$) 2.7σ high

Is CKM model in question?

arXiv:1104.2117 [hep-ph]

  - We take simple averages of two fits to predict cu triangle.
- It is important to check the CKM paradigm for up-type quarks as it has been in down-quark sector.

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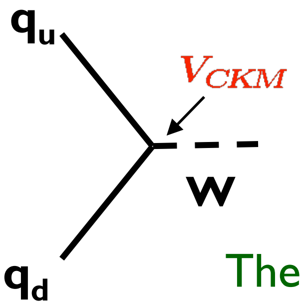
CPV and CKM

- CPV requires weak phases - in SM these come from CKM



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Usually use Wolfenstein parameters

$\lambda=\sin\theta_C, A, \rho, \eta$ (θ_c=Cabibbo angle)

Expand in powers of λ.

$O(\lambda^3)$ OK

There are 6 unitarity triangles – most common is "*bd*"

- Buras parameters
  - *Ensure unitarity of "bd" triangle at all orders in λ*

[Phys. Rev. D50, 3433 (1994)]

$$\bar{\rho} = \rho(1 - \lambda^2/2 + \mathcal{O}(\lambda^4))$$
$$\bar{\eta} = \eta(1 - \lambda^2/2 + \mathcal{O}(\lambda^4))$$

Coordinates of apex of *bd* triangle

- For charm decays, most interest is in "*cu*" triangle.

$O(\lambda^5)$ Needed

Phase in V_{cd} appears at order λ^5

$$\begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta})(1+\boxed{\lambda^2/2)} \\ -\lambda+A^2\lambda^5[1-2(\bar{\rho}+i\bar{\eta})] & 1-\lambda^2/2-\lambda^4(1+4A^2)/8 & A\lambda^2 \\ A\lambda^3[1-(\bar{\rho}+i\bar{\eta})] & -A\lambda^2+A\lambda^4[1-2(\bar{\rho}+i\bar{\eta})]/2 & 1-A^2\lambda^4/2 \end{pmatrix} + \mathcal{O}(\lambda^6)$$

- NOTE – phase of V_{ub} is still γ despite λ^5 term

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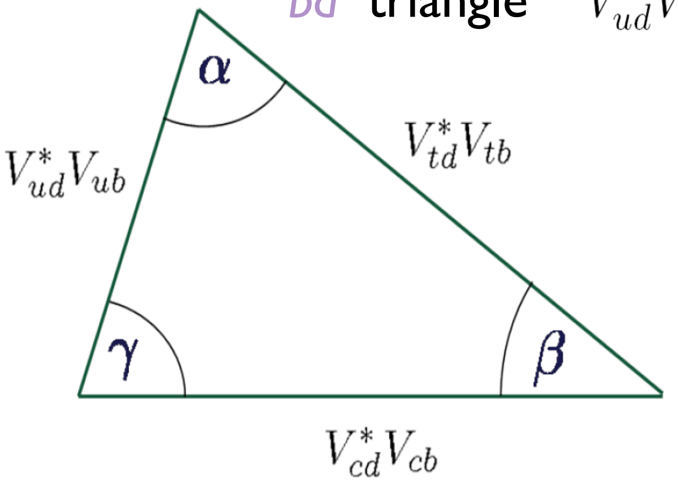
Unitarity Triangles from CKM Fits

bd triangle $V_{ud}^* V_{ub} + V_{cd}^* V_{cb} + V_{td}^* V_{tb} = 0$

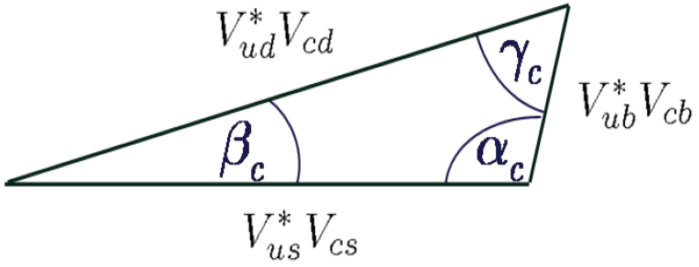


$$\alpha = [V_{td}V_{tb}^*/V_{ud}V_{ub}^*] = (89.4 \pm 4.3)^\circ$$
$$\beta = [V_{cd}V_{cb}^*/V_{cd}V_{cb}^*] = (22.1 \pm 0.6)^\circ$$
$$\gamma = [V_{ud}V_{ub}^*/V_{cd}V_{cb}^*] = (68.4 \pm 3.7)^\circ$$

NOTE that

- γ_c is equal to γ
- $\alpha_c + \gamma_c \sim 90^0$

$V_{ud}^* V_{cd} + V_{us}^* V_{cs} + V_{ub}^* V_{cb} = 0$ *cu* triangle



$$\alpha_c = [V_{ub}^* V_{cb}/V_{us}^* V_{cs}] = (111.5 \pm 4.2)^\circ$$
$$\beta_c = [V_{ud}^* V_{cd}/V_{us}^* V_{cs}] = (0.0350 \pm 0.0001)^\circ$$
$$\gamma_c = [V_{ub}^* V_{cb}/V_{ud}^* V_{cd}] = (68.4 \pm 0.1)^\circ$$

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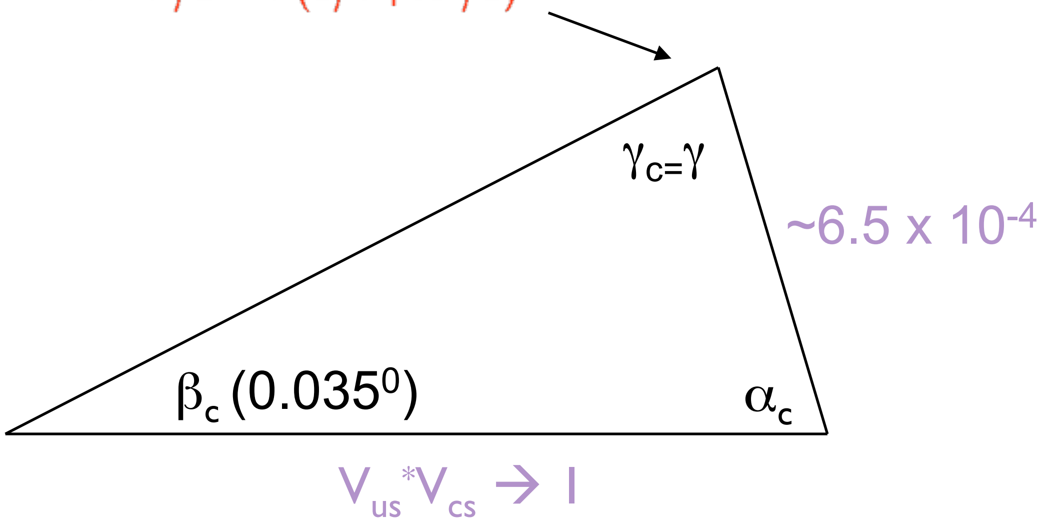
Constraint on cu Triangle ?

$$1+\frac{A^2\lambda^5(\bar{\rho}+i\bar{\eta})}{\lambda-\lambda^3/2-\lambda^5(1/8+A^2/2)}=1.00025+i1.00062$$



Lengths of sides:

CKM	Uncertainty
$\lvert V_{ud}\rvert$	0.022%
$\lvert V_{cd}\rvert$	4.8%
$\lvert V_{ub}\rvert$	11%
$\lvert V_{cb}\rvert$	3.2%
$\lvert V_{us}\rvert$	1%
$\lvert V_{cs}\rvert$	3.5%

Might improve SL decays of D_s with run at D_s threshold ?

→ Some measurement of β_c is needed to test CKM

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Decays to CP Eigenstates

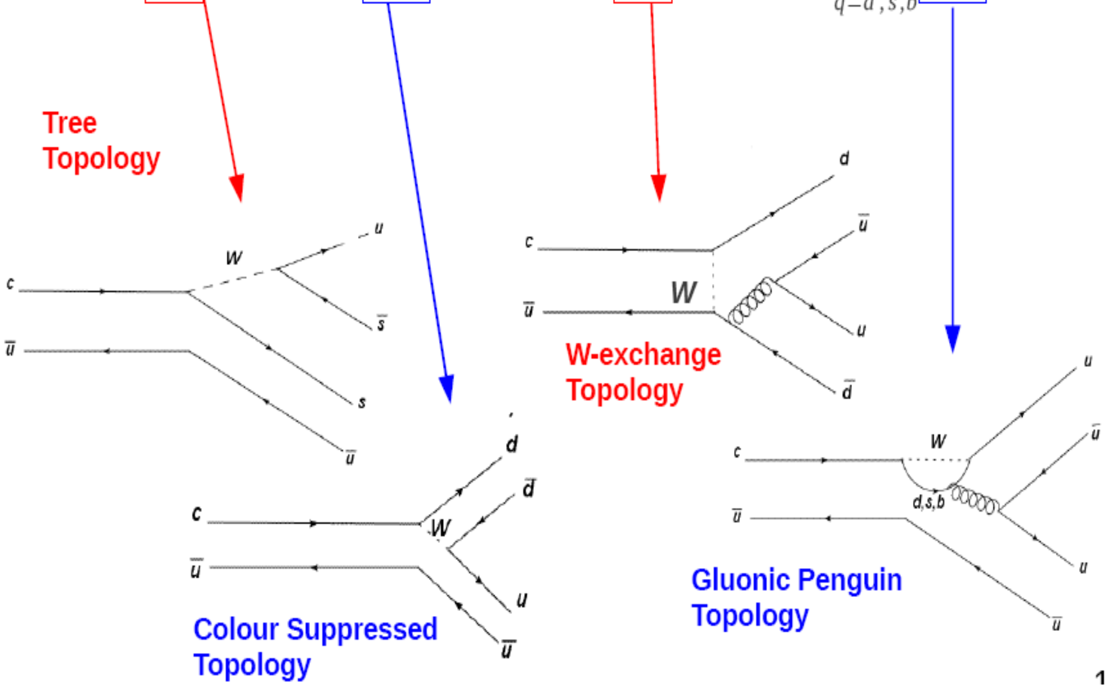
- For decays to CP eigenstates, strong phase δ in λ_f is zero

Several amplitudes could, however, contribute to the decays.

- Some information on the magnitude of **P**, the penguin contribution can be obtained from an isospin analysis if all charge modes have well measured **BF**'s, including neutralmodes $\pi^0\pi^0$, $\rho^0\rho^0$ and all the $\rho\pi$ modes too.

This is best done at the electron machines.

$$A = \boxed{|T|}\, e^{i(\phi_T+\delta_T)} + \boxed{|CS|}\, e^{i(\phi_{CS}+\delta_{CS})} + \boxed{|W|}\, e^{i(\phi_W+\delta_W)} + \sum_{q=d,s,b} \boxed{|P_q|}\, e^{(i\phi_q+\delta_q)}$$



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$D^0 \rightarrow f_{CP}$ Decay Amplitudes

- To order λ^6 these are:

Four out of five are complex !

$$
\begin{aligned}
V_{cs}V_{us}^* &= \lambda - \frac{\lambda^3}{2} - \left(\frac{1}{8} + \frac{A^2}{2}\right)\lambda^5 \\
V_{cs}V_{ud}^* &= 1 - \lambda^2 - \frac{A^2\lambda^4}{2} + A^2\lambda^6\left[\frac{1}{2} - \bar{\rho} - \boxed{i\bar{\eta}} - \bar{\eta}^2 - \bar{\rho}^2\right] \\
&\boxed{V_{cd}V_{ud}^* = -\lambda + \frac{\lambda^3}{2} + \frac{\lambda^5}{8} + \frac{A^2\lambda^5}{2}[1 - 2(\bar{\rho} + i\bar{\eta})]} \\
V_{cd}V_{us}^* &= -\lambda^2 + \frac{A^2\lambda^6}{2}[1 - 2(\bar{\rho} + i\bar{\eta})] \\
V_{cb}V_{ub}^* &= A^2\lambda^5(\bar{\rho} + i\bar{\eta})
\end{aligned}
$$

Real

Phase is $O(\lambda^6)$

Phase is $\pi-\beta_c$

Phase is $\pi-\beta_c$ but $\sim\lambda^6$

Phase is γ_c, but only found in penguin amplitude
→unlikely to be able to
check that $\gamma_c=\gamma$

Most promising ?
$D^0 \rightarrow hh$ $(h = \pi, K, \rho, f_0, \ldots)$

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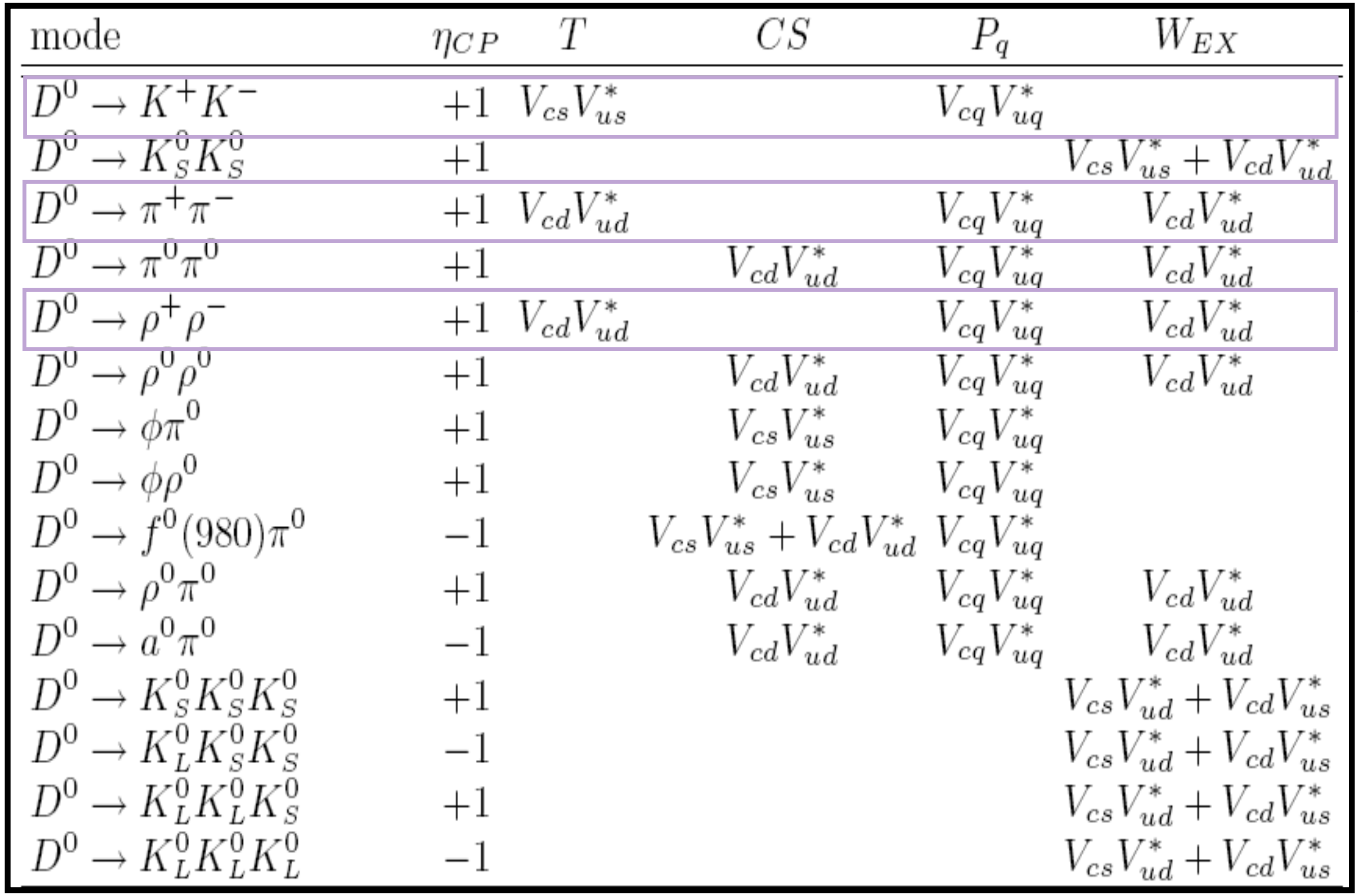
Amplitudes for Decays to CP Eigenstates



mode	η_{CP}	T	CS	P_q	W_{EX}
$D^0 \to K^+K^-$	$+1$	$V_{cs}V^*_{us}$		$V_{cq}V^*_{uq}$	
$D^0 \to K^0_SK^0_S$	$+1$				$V_{cs}V^*_{us} + V_{cd}V^*_{ud}$
$D^0 \to \pi^+\pi^-$	$+1$	$V_{cd}V^*_{ud}$		$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \to \pi^0\pi^0$	$+1$		$V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \to \rho^+\rho^-$	$+1$	$V_{cd}V^*_{ud}$		$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \to \rho^0\rho^0$	$+1$		$V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \to \phi\pi^0$	$+1$		$V_{cs}V^*_{us}$	$V_{cq}V^*_{uq}$	
$D^0 \to \phi\rho^0$	$+1$		$V_{cs}V^*_{us}$	$V_{cq}V^*_{uq}$	
$D^0 \to f^0(980)\pi^0$	-1		$V_{cs}V^*_{us} + V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	
$D^0 \to \rho^0\pi^0$	$+1$		$V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \to a^0\pi^0$	-1		$V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \to K^0_SK^0_SK^0_S$	$+1$				$V_{cs}V^*_{ud} + V_{cd}V^*_{us}$
$D^0 \to K^0_LK^0_SK^0_S$	-1				$V_{cs}V^*_{ud} + V_{cd}V^*_{us}$
$D^0 \to K^0_LK^0_LK^0_S$	$+1$				$V_{cs}V^*_{ud} + V_{cd}V^*_{us}$
$D^0 \to K^0_LK^0_LK^0_L$	-1				$V_{cs}V^*_{ud} + V_{cd}V^*_{us}$

Dominated by real T

Dominated by T with $\phi_f = \pi - \beta_c$

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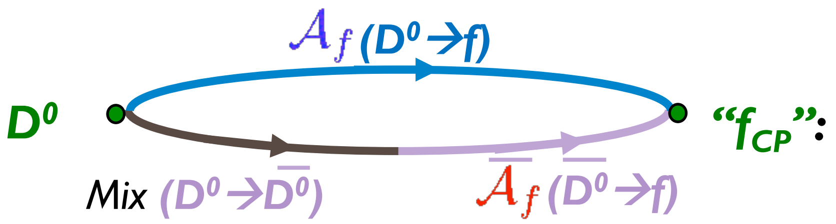
Time-Dependence for D^0 Decays

- The time-dependences for decay rates $\Gamma(\overline{\Gamma})$ for $D^0(\overline{D}^0)$ differ



$\mathcal{A}_f$ ($D^0 \rightarrow f$)

D^0

"f_{CP}":

Mix ($D^0 \rightarrow \overline{D}^0$)

$\overline{\mathcal{A}}_f$ ($\overline{D}^0 \rightarrow f$)

CP eigenstates are also accessible to D^0 or $\overline{D}^0$

$$\Gamma \propto e^{-\Gamma\Delta t}\left[\cosh(y\Gamma t) + \frac{Re(\lambda_f)}{1+|\lambda_f|^2}\sinh(y\Gamma t) + \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos(x\Gamma t) - \frac{2Im(\lambda_f)}{1+|\lambda_f|^2}\sin(x\Gamma t)\right]$$

$$\bar{\Gamma} \propto e^{-\Gamma\Delta t}\left[\cosh(y\Gamma t) + \frac{Re(\lambda_f)}{1+|\lambda_f|^2}\sinh(y\Gamma t) - \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos(x\Gamma t) + \frac{2Im(\lambda_f)}{1+|\lambda_f|^2}\sin(x\Gamma t)\right]$$

- In decays to *CP* states, strong phase for D^0 is same as $\overline{D}^0$ so

$$\lambda_f = \frac{q\bar{\mathcal{A}}_f}{p\mathcal{A}_f} \propto e^{i(\phi_M - 2\phi_f)}$$

mixing

Weak decay

To measure weak phase ϕ_f
we MUST know ϕ_M

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Time-Dependent CP Asymmetry

- Define this as

$$A_{CP} = \frac{\bar{\Gamma} - \Gamma}{\bar{\Gamma} + \Gamma} = -\eta_{CP} \frac{(1 - |\lambda_f|^2)\cos(x\Gamma t) - 2Im(\lambda_f)\sin(x\Gamma t)}{(1 + |\lambda_f|^2)\cosh(y\Gamma t) + Re(\lambda_f)\sinh(y\Gamma t)}$$

- Decay to CP eigenstate dominated by single process, $|\lambda_f|=1$

$$A_{CP} = \frac{\bar{\Gamma} - \Gamma}{\bar{\Gamma} + \Gamma} = -\eta_{CP} \frac{Im(\lambda_f)\sin(x\Gamma t)}{\cosh(y\Gamma t) + Re(\lambda_f)\sinh(y\Gamma t)}$$

- For B decay (if we assume that $y_B=0$ and $|\lambda_f|=1$) this is

$$A_{CP} = -\eta_{CP}\sin(\arg\lambda_f)\sin(x\Gamma t)$$

Familiar to all
B factory practitioners

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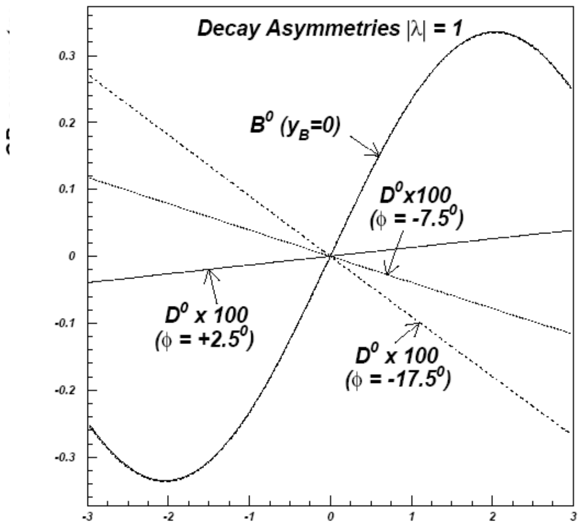
Time-Dependent CP Asymmetry

- For D decay we measure CP asymmetry vs. decay time

$$A_{CP} = \frac{\bar{\Gamma} - \Gamma}{\bar{\Gamma} + \Gamma} = -\eta_{CP} \frac{(1 - |\lambda_f|^2)\cos(x\Gamma t) - 2\Im(\lambda_f)\sin(x\Gamma t)}{(1 + |\lambda_f|^2)\cosh(y\Gamma t) + \Re(\lambda_f)\sinh(y\Gamma t)}$$



- The D^0 asymmetry is much smaller than that for B^0
- $|A_{CP}|$ is almost linear in t while, for B^0 it is sinusoidal
- Slope of line depends upon ϕ = Arg $\{\lambda\}$
- $|A_{CP}|$ is largest at large $|t|$
- But as $|t|$ grows larger, the number of events falls off exponentially.

Any asymmetry at t~0 is from direct CPV

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Mis-Tagging

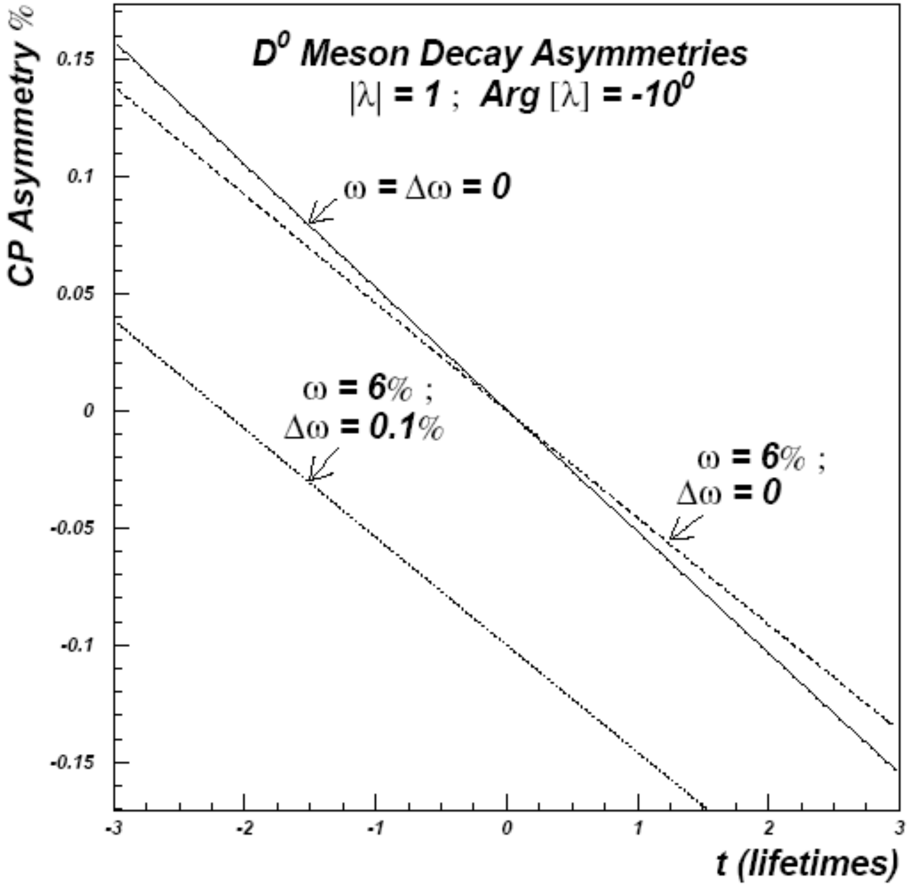
- Effect of mis-tagging probability ω is to reduce the D^0-D^0 asymmetry
- Effect of *CP* asymmetry in ω is to shift the asymmetry.
  - Direct CPV asymmetry is measured at t=0 ! So shift is particularly serious in this case.

$$\boxed{\begin{aligned}\mathcal{A}^{\rm Phys}(\Delta t) &= \frac{\bar{\Gamma}^{\rm Phys}(\Delta t) - \Gamma^{\rm Phys}(\Delta t)}{\bar{\Gamma}^{\rm Phys}(\Delta t) + \Gamma^{\rm Phys}(\Delta t)} \\ &= -\Delta\omega + (1-2\omega+\Delta\omega)\mathcal{A}(\Delta t)\end{aligned}}$$

Mis-Tagging

- Effect of mis-tagging probability ω is to reduce the D^0-D^0 asymmetry

- Effect of *CP* asymmetry in ω is to shift the asymmetry.
  - Direct *CPV* asymmetry is measured at $t=0$! So shift is particularly serious in this case.



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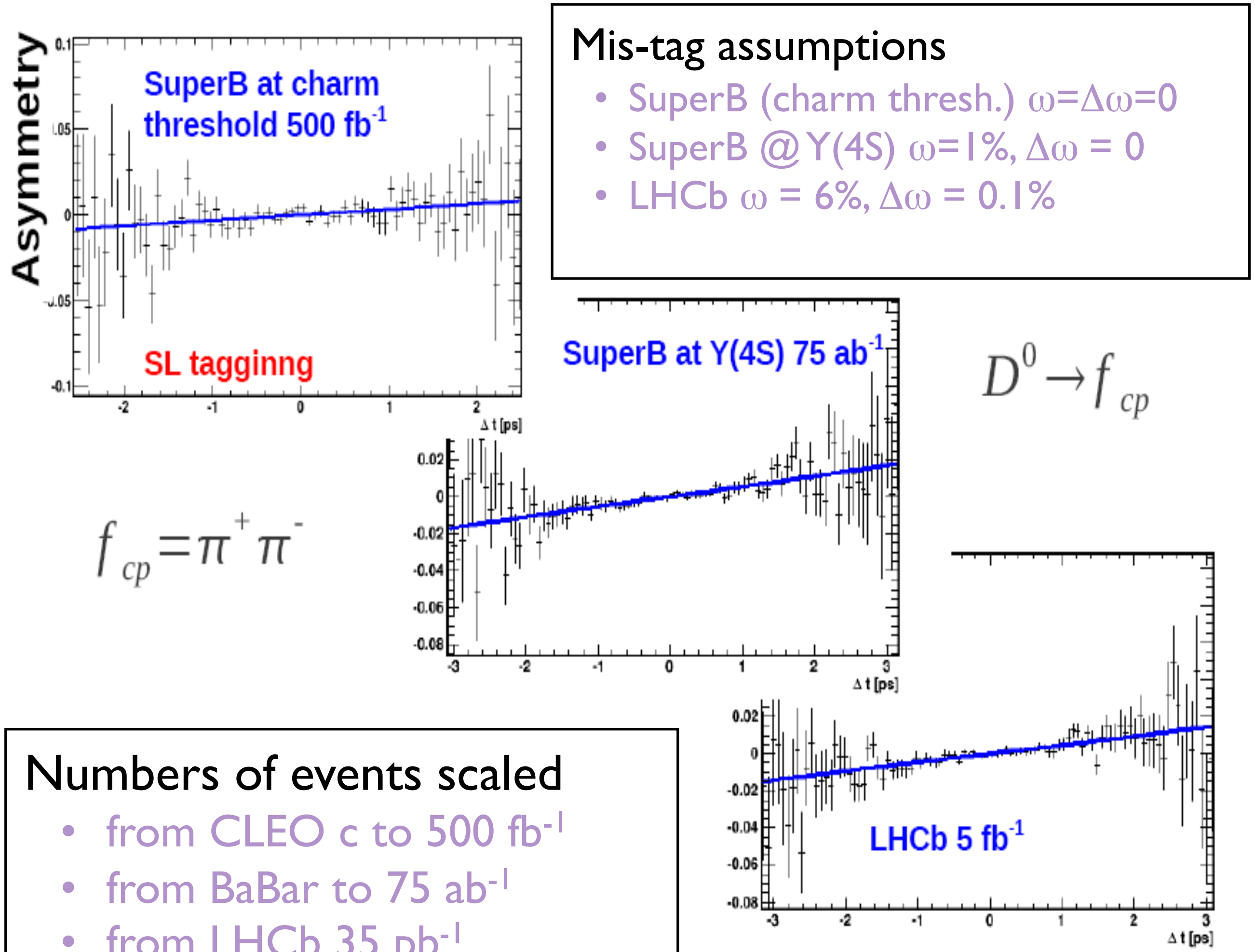
Results – "as good as (they) get"

- A toy MC study was made to study how well we might measure $\phi=\mathrm{Arg}\{\lambda\}$
  - Events were generated with the distributions $\Gamma(\Delta t)$ and $\Gamma(\Delta t)$
  - Perfect time resolution was assumed
- Unbinned likelihood fits were made to study $\sigma(\phi)$.



$f_{cp}=\pi^{+}\pi^{-}$

$D^{0}\rightarrow f_{cp}$

Mis-tag assumptions

- SuperB (charm thresh.) $\omega=\Delta\omega=0$
- SuperB @ Y(4S) $\omega=1\%$, $\Delta\omega = 0$
- LHCb $\omega = 6\%$, $\Delta\omega = 0.1\%$

Numbers of events scaled

- from CLEO c to 500 fb^{-1}
- from BaBar to 75 ab^{-1}
- from LHCb 35 pb^{-1}

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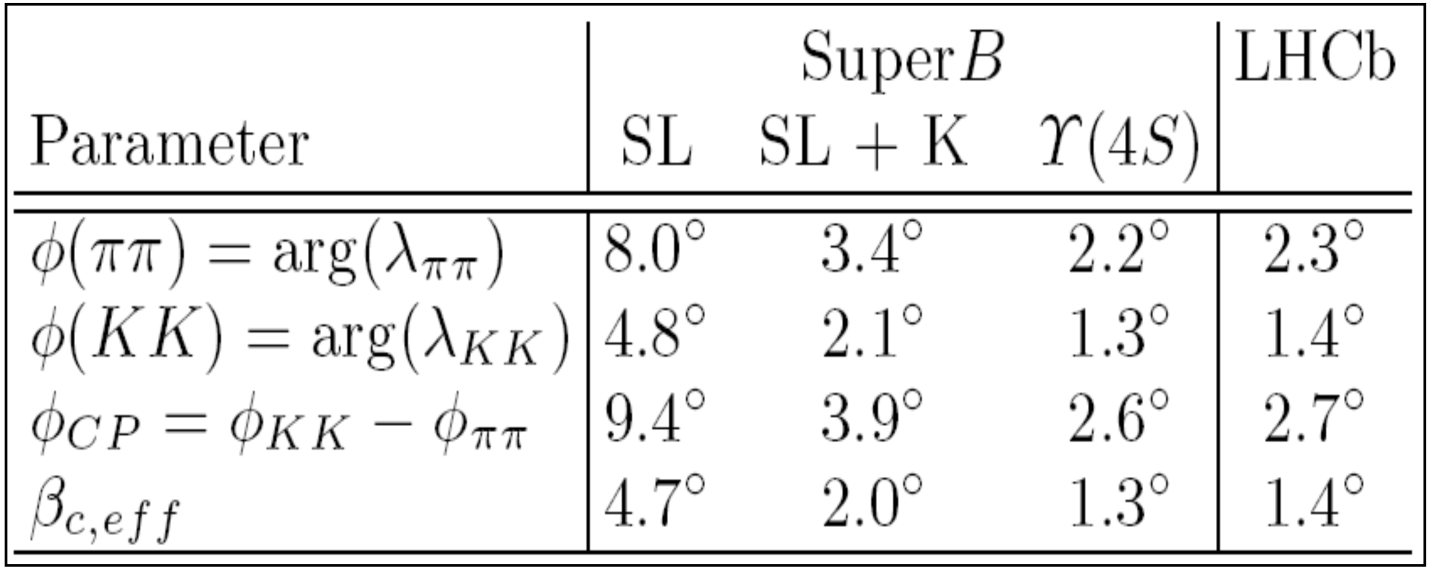
Results – “as good as (they) get”

- The K^+K^- mode is dominated by a tree diagram that is real.

  So we expect that no direct CPV will be found here
- Therefore, this mode can be used to find $\arg(q/p) = \phi_M$
- Then $\pi^+\pi^-$ mode (for which $\arg(\lambda_f\} = \phi_M-2\beta_{C,eff}$) can give $\beta_{C,eff}$



	Super$B$			LHCb
Parameter	SL	SL + K	$\Upsilon(4S)$	
$\phi(\pi\pi) = \arg(\lambda_{\pi\pi})$	8.0°	3.4°	2.2°	2.3°
$\phi(KK) = \arg(\lambda_{KK})$	4.8°	2.1°	1.3°	1.4°
$\phi_{CP} = \phi_{KK} - \phi_{\pi\pi}$	9.4°	3.9°	2.6°	2.7°
$\beta_{c,eff}$	4.7°	2.0°	1.3°	1.4°

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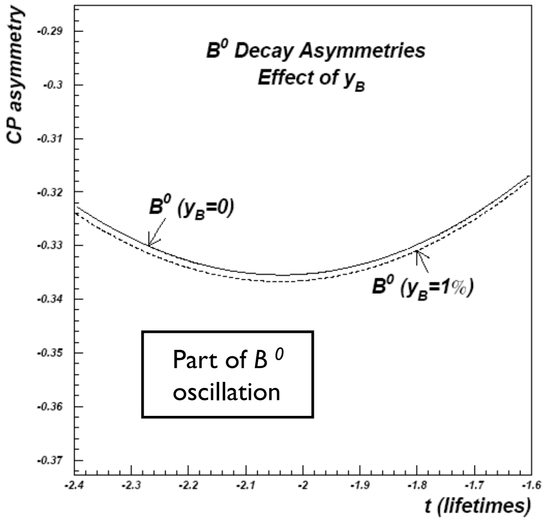
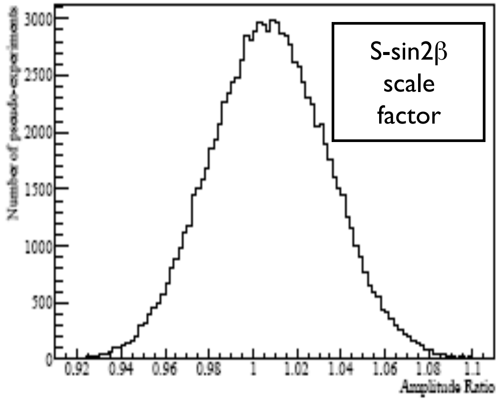
Effect of "y_B" on CP Asymmetry

- In Babar, it was assumed, in the measurement of $S = \sin 2\beta$ from B^0 decays, that $y_B = 0.0$.
- The PDG specifies a value of $\sim 0.01 \pm 0.035$
- Assuming this is Gaussian we estimate it makes a difference to $S = \sin 2\beta$ of $\sim 0.007 \pm 0.027$
- This is comparable to the expected statistical precision of measurements from both LHCb and SuperB



Part of B^0 oscillation



S-sin2β scale factor

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Epilogue

We recall what Ikaros Bigi has often reminded us,

"The goal in charm physics is not just to observe CPV in D decays - but also to understand its origin !"

- SuperB, Belle2 and LHCb, asymmetries in x_D, y_D, x'_D, y_D', *etc.* should provide a good probe for CPV in mixing.
- This should also be possible for a variety of decay modes and maybe provide a clue whether CPV is in mixing alone.
- A TDCPV "sin2β_c" measurement will be much harder for D's than it was for B's.

  However, such an analysis brings with it an excellent way to measure the (extremely important) D^0 *"mixing phase"* ϕ_M *phase using* $D^0 \rightarrow K^+K^-$ *decays.*
- Improved constraints on trangle sides can come from charm threshold runs.
- This can also be done at charm threshold, at the Y(4S) and at LHCb though the former is cleaner
- Charm threshold runs will improve our knowledge of strong phases needed for all D^0 mixing measurements (and CKM γ).
- We also note that CKM phase measurements for B^0 must include better estimates for y_B.

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